WATER RESOURCES SYMPOSIUM

40th ANZAAS CONGRESS

PROCEEDINGS - PART 2

lincoln papers
in
water resources

2

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FOREWORD

Lincoln College, the College of Agriculture of the University of Canterbury, sponsors an active research and teaching programme in hydrology, soil conservation and water resources development. The purpose of these Papers is to communicate research results and new developments in these fields as rapidly as possible, and particularly to report the results of projects undertaken in conjunction by the Department of Agricultural Engineering and the New Zealand Agricultural Engineering Institute. From time to time the opportunity will be taken to publish material originating elsewhere in New Zealand with which the College is associated and which could not otherwise be made available.

The Lincoln Papers in Water Resources are published by the New Zealand Agricultural Engineering Institute and printed by the Lincoln College Press. All enquiries should be addressed to the Information Officer, New Zealand Agricultural Engineering Institute, Lincoln College Post Office, Canterbury, New Zealand.

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PREFACE

Volumes 1 and 2 of the Lincoln Papers in Water Resources comprise the papers presented at a Symposium on Water Resources Development which was arranged by the Engineering Section of the 40th ANZAAS Congress and organised by Lincoln College Staff. The full programme for the Symposium was as follows:

<u>Thursday 25th January</u>

Chairman: F.M. Henderson, University of Canterbury

(a) The Atmospheric Phase

1. Hydrometeorological contribution to the development and control of water resources - D.N. Body, Commonwealth Bureau of Meteorology.

2. Estimating the probable maximum precipitation in remote areas - C.J. Wiesner, University of New South Wales.

3. Rainfall variability and reliability in New Zealand - J. Coulter, N.Z. Meteorological Service.

Chairman: J.R. Burton, Lincoln College

(b) The Land Use Phase

4. Effects of agricultural land use on water quality - K. O'Connor, D.S.I.R., Lincoln.

5. Watershed management - problems and possibilities - J.F. Holloway, N.Z. Forest Service.

6. Evaluation of changes in the land-use regime - W.C. Boughton, Lincoln College.

<u>Friday 26th January</u>

Chairman: J.R. Burton, Lincoln College

(c) The Control Phase

7. Theory and practice in water resource system design - D.T. Howell, University of New South Wales.

8. The Tongariro Power project - H. James, Ministry of Works.

9. Irrigation development in the New Zealand environment - R. Lobb, N.Z. Department of Agriculture.

Chairman: T.D.J. Leech, Cooma, New South Wales.

(d) The Socio-Economic Phase

10. Economic evaluation for water resources development - R. Jensen, Lincoln College.

11. Legislation for water resources development - D.G. McGill, Ministry of Works.

12. Education for water resources development - J.R. Burton, Lincoln College.

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ABSTRACTS OF PAPERS

THEORY AND PRACTICE IN WATER-RESOURCE SYSTEM DESIGN

Mr. D.T. Howell,
Senior Lecturer, School of Civil Engineering,
University of New South Wales, Australia.

Recent political developments in Australia have led to a number of benefit-cost studies being carried out so that water-resource development proposals can be examined with regard to economic efficiency.

In this paper a number of methods of various levels of sophistication devised for some of these ad hoc studies are described and reviewed critically. Current developments to improve techniques for the design of water-resource systems are outlined.

THE TONGARIRO POWER PROJECT

Mr. H. James,
Power Division, Ministry of Works,
Wellington, New Zealand.

Abstract Not Available.

IRRIGATION DEVELOPMENT IN THE NEW ZEALAND ENVIRONMENT.

Mr. W.R. Lobb,
Superintendent, Winchmore Irrigation Research Station, Ashburton.

Unlike most irrigation areas New Zealand has developed its initial irrigation schemes during a period when its agricultural products entering world trade have been almost entirely derived from animal products. Also, the climate is one in which an economically reliable agricultural enterprise can be supported without irrigation. However, soil moisture deficits do occur, for the most part on the East Coast regions and the inland central areas of the South Island. These deficits can be quite critical and even with a 30" average rainfall, as in Canterbury, can result in an average of 59 drought days during a growing season of 250 days.

Measured production increases of 100% for pasture and animal products result from the use of efficient irrigation. To do this a low cost reliable water source is necessary and cheap methods of efficient flood irrigation which require little labour have been designed. A labour efficiency of an acre irrigated per man-minute has been achieved.

ECONOMIC EVALUATION FOR WATER RESOURCES DEVELOPMENT

Mr. R. Jensen,
Lecturer, Agricultural Economics Department,
Lincoln College.

This paper attempts three tasks: first, to demonstrate that there could be a conflict between the economist's ideal of optimum allocation of public funds and the engineer's ideal of optimisation within the conceptual unit of the watershed; second, to discuss briefly the techniques applicable to economic evaluation and planning of water resources development; and third, to comment on the information available and some institutional aspects, of water resources evaluation and planning in New Zealand. The author argues that the various professions concerned with water resources development in New Zealand should be given the opportunity to adopt a modern approach to this vital question.

LEGISLATION FOR WATER RESOURCES DEVELOPMENT

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Ministry of Works, Wellington, New Zealand.

The law relating to water in New Zealand is to be found either in the Common Law as derived from the Common Law of England or in many different Acts of Parliament administered by some ten Government Departments.

The ever increasing demand for water for generating electricity, for irrigation and for industrial, domestic and other uses - the need for ensuring that water is not wasted but is conserved and used to the best advantage in the public interest - and the change in accent from mining to irrigation have made it necessary to vest in the Crown by the Water and Soil Conservation Act 1967, the sole right to use natural water and to consider to what extent the numerous enactments relating to water should be consolidated, revised or repealed.

These many conflicting increasing uses of water have made it apparent that there is a vital need to co-ordinate and control the water resources of this country. The new Act endeavours to achieve this by constituting Regional Water Boards and a National Water and Soil Conservation Authority whose functions include the allocation control and conservation of natural water and the overall control of bodies dealing with natural water.

EDUCATION FOR WATER RESOURCES DEVELOPMENT

Professor J.R. Burton,
Department of Agricultural Engineering,
Lincoln College, Canterbury, New Zealand.

Australia and New Zealand face many similar problems because of their geographic isolation, national and political background and dependence on agricultural production. These similarities are briefly discussed.

In the context of water resources development the two countries are quite dis-similar. At the same time both countries face essentially similar problems in that water resources development is a factor of major national importance and that there is an urgent need for the education and training of a variety of water resources specialists. The nature of the water resource problems facing Australia and New Zealand is compared and contrasted and the situation regarding the availability of trained water resources personnel is critically discussed.

The special educational needs of water resources specialists are described and existing University courses discussed critically. New proposals for water resources education in New Zealand are outlined. It is contended that education for water resources development is best provided at Graduate level with a minimum requirement of one year's formal post-graduate class work. Where possible this should be supplemented by a research project and lead to the award of a masterate or doctorate. Because of the inter-disciplinary nature of practical water resources development problems, the educational programme should accept graduates from a variety of disciplines and aim to produce specialists having a common interest and understanding capable of contributing to the activities of a water resources development team. The problems of academic isolation and the needs for international exchange of students, staff and ideas are also discussed.

THEORY AND PRACTICE IN WATER-RESOURCE SYSTEM DESIGN

D.T. Howell, Senior Lecturer,
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The University of New South Wales.

INTRODUCTION

This paper is intended to be a brief review of some of the problems, both theoretical and practical, which now confront those who attempt rational design of water-resource systems. Rational design includes the processes of choosing the size of various system components, like dams, spillways, floodgates, aqueducts and pipelines, and deciding how the system components should be operated, e.g., establishing rules for releasing water through dams for irrigation and before and during floods. These choices and decisions are always made in terms of some criterion and criteria. Further phases of rational design are the choice among different possibilities in a given river basin, such as the use of different mutually exclusive damsites, and the ordering of priorities among systems in different basins.

Many of these phases are currently decided on without analysis, but we can expect analysis to make inroads into all of them, even those which remain the preserve of the political decision-maker.

In Australia the Federal Government has recently entered into a commitment to provide funds to the states for water resources development projects. This has led the states to evaluate a number of proposals by benefit/cost analysis. Such work is somewhat novel in Australia and presents a number of problems. We can term this field of work "hydro-economic" in some recognition that it must be carried out by a team from a number of different disciplines. We find that a number of problems lie mainly in the field of hydrology while many raise predominantly economic issues. A few of the problems encountered will be discussed, but the purely economic ones will be avoided. However, it is difficult to separate engineering and economics here.

THEORETICAL DEVELOPMENTS

There exists a body of theory which (at least in theory!) enables us, after a necessarily large amount of computation, to select best or "optimal" designs of water-resource systems. It depends on a theory of investment analysis arising out of production economics theory, and its application depends on the use of techniques of operations research made feasible by the electronic digital computer.

An account of how to design in pursuit of an economic efficiency objective or other objectives like income redistribution is given in the Harvard "blue" book (i) (See references at end of paper). A general guide to an approach to investment analysis has been given in an Australian Treasury White Paper (2).

The final evaluation of project designs in terms of an economic efficiency objective comes down to an evaluation of benefits and costs as they are ordinarily understood. A typical simple problem is to decide how big to build a dam at a particular site on a river, and in most circumstances the best size is that size which gives the greatest excess of benefits over costs.

Water-resource systems present special problems compared with many other development projects because of the awkward stochastic nature of hydrologic phenomena. A water-resource system includes engineering works to regulate and transport water from sources of supply to centres of demand. The supply of water is stochastic, varying in time, exhibiting some trends but with a great deal of randomness. The demand for water is also stochastic.

It is possible in many cases to give a reasonable characterisation in terms of a time series model of the properties of the stochastic water supply, e.g. the varying inflow from a river into a reservoir. It is often possible to characterise in a similar way fluctuating urban water consumption. Irrigation water "requirements" can be similarly treated in terms of fluctuations of potential evapotranspiration. It is at present much more difficult to give an account of irrigation water "demand" which amounts to evaluating the benefits in dollars achieved from meeting "requirements" for irrigation water to different degrees short of 100%, as will be discussed later.

Once the benefits from a regulated supply of water are evaluated, that is, once a "benefit function" is established, whatever approach is used, it is then theoretically possible to optimize both reservoir operation and reservoir size. From a thorough going "demand" approach there can result an optimal allocation of water in time throughout an irrigation season as a function of current reservoir contents, an optimal tactical policy as to what acreage to sow at the beginning of a season and what proportion of irrigated acreage to abandon at the onset of water rationing, and what allocation of water to make among different activities.

If demand can be projected into the future (it is obviously not steady in time), then it becomes possible over a planning period to maximize the excess of the expected value of the present worth of benefits over the present worth of costs at an appropriate discount rate. This produces, in general, a best system design with economic efficiency as an objective. It is possible to complete the same sort of analysis for objectives like income redistribution, population redistribution ("decentralisation") and variously weighted mixes of more than one objective.

A theoretical framework exists then for optimizing operating policy decisions and the size of system components. Policy decisions include rules for releasing water from reservoirs, what area to irrigate from a reservoir, what proportion of reservoir storage should be kept empty for flood control, how spillway gates should be operated before and during floods, what releases for hydro-electric energy should be made in winter at the expense of irrigation in the following summer, and at what rate aquifer recharge should be made. The sizing of system components includes finding the best height of dam at a particular site and hence best reservoir capacity, fixing controlled outlet capacity, including floodgate capacity, setting fixed geometry spillway capacity and head-discharge characteristic, fixing aqueduct capacity, fixing the total area to be served by an irrigation reticulation and drainage system, and fixing the capacity of aquifer recharge facilities.

Problems like these and more complex ones including those involving water quality have at least a theoretical basis developed for their solution. Some at least of this theory can be put into practice by means of numerical experiment with computer simulation. Ideally, streamflows, reservoir releases, spillway discharges, rainfall, evapotranspiration, and even plant growth and economic and social change can all be simulated. Other techniques of operations research like linear programming and dynamic programming can in some cases reduce the computational burden.

PRACTICE

When we come to perform a specific analysis or to attempt an ordering of priorities, we find that the state of the art we have so far developed from the theoretical background leaves much to be desired. Theory and practice are widely separated.

What streamflow records we have we can augment wherever possible with the standard techniques of hydrology. We can investigate the smoothing, or the sometimes desired lumping, effect on streamflow of reservoirs of different capacity with the help of a computer. We can use just a single record of streamflow, an augmented historical record, or we can in many cases find a suitable mathematical model to describe the streamflow. In these cases we can investigate reservoir behaviour with a number of sampled simulated records.

We can estimate with various degrees of apparent success the benefits achieved from making regulated flows of water available to various activities like irrigation, urban and industrial uses, and hydro-electric energy generation.

Irrigation is Australia's largest use of regulated water and appears as the main source of likely benefit from proposed water-resource systems. It is possible to estimate irrigation benefits from regulated flows with 100% reliability but there is difficulty in estimating the effects of restricted supplies and complete failure of supply. These benefit estimates depend on projections into the future of market prices for irrigation products. We have also to estimate the rate at which irrigation will be taken up and the pattern of irrigated products which will emerge influenced by market prices and legal, institutional and social constraints.

We can estimate engineering costs, though not well, better than anything else in the analysis. Then, with interest rates which "seem to have been appropriate" (2) we can determine the excess of benefits over costs for various system designs and choose the best design.

DIFFICULTIES ARISING IN PRACTICE

What is currently being done can be seen to fall a good deal short of what is capable of being done. Even so, there are difficulties with what is currently being done.

The use of streamflow records, which have been augmented by streamflow-to-streamflow correlation, rainfall-to-streamflow correlation or by some other method, gives rise to uncertainty in the estimation of reservoir yield. The errors which arise in streamflow are unknown, and even sensitivity studies to determine the effects of arbitrarily assigned hypothetical errors cannot eradicate this source of uncertainty.

It is still common practice to use only a single sequence of streamflow record of short duration (only a few tens of years, for instance). This gives rise to further uncertainty because the size of the sampling error in reservoir yield remains unknown. The greater the persistance (or serial correlation) in the streamflow the greater is the probability of a large sampling error.

If, on the other hand, a stochastic streamflow model is used to simulate a large sample of records to bring this sampling error down to a suitable size, then there remains the possibility of noise, additional unknown error, being introduced from an ill-fitting model.

Further, it is still common practice to estimate a reservoir yield which is 100% reliable. Any such estimate must be highly uncertain - whatever value of yield results from such a calculation is unstable. The true value should in fact be zero for nearly all Australian rivers. Regulated yields with reliabilities of less than 100% can be estimated quite reasonably.

To explore by trial different ways of operating reservoirs, i.e. different release rules, is a large task, and it is only in a few special circumstances that techniques of rapid optimization have been developed. In general, arbitrary assumptions are made about the type of release rule to be made. How significant this is in practical situations in Australia is not yet known.

Once the release rule is decided, there still remains, in the case of a reservoir providing regulated flow for irrigation, the question of how best to compromise between large irrigated acreages at low reliability and small irrigated acreages at high reliability. We have tried to deal with this question by estimating the losses or penalties arising from shortfalls below full "requirements" of irrigation.

The demand function approach to this problem has been initially developed by Flinn and is being carried further by Dudley both at the University of New England in Armidale, New South Wales. It is discussed in the next section. Until this approach is further developed the effect of water shortfalls can be estimated either

(i) by expressing average effects of occasional shortfalls by means of a factor which when multiplied by the benefit with 100% reliability of full supply gives the expected or time-average benefit, or (ii) by a commonsense evaluation of the consequences of failures of supply or reductions in supply at different times in the growing period of irrigated crops. In this second case, the penalties of different types of failure are totalled for a simulation run. The total penalty is subtracted from the benefit with 100% reliability of full supply for the same period to give the expected benefit. We have in one case involving livestock production with irrigated pasture estimated the penalties by finding the costs of purchasing and transporting the fodder not produced on the irrigated area in times of water shortage.

The foreoing discussion has implied an objective of maximizing expected benefit. However, even though neither farmers' nor the community's risk aversions are well known, they are not likely to be negligible, and some account of preferences for more certain and less risky returns needs to be taken.

The benefits achieved are very sensitive both to the projected rate of growth of irrigation once a dam is built and to the allocation of the irrigation water to different irrigation activities which develops. It is here that the greatest uncertainty of all exists. The useful life of a dam or any other civil engineering component of a water-resource system is long. Markets for irrigated commodities change with time, often almost unpredictably, often as the result of governmental action. The rate of development of irrigation depends not only on the demand for irrigated products but also on legal, institutional and social factors. Examples of these are government-imposed limits on licensed irrigated areas, existing sizes of land holdings (and whether they are company or family controlled) and the personal readiness of farm operators to change their practices. It is difficult to make predictions in the face of all the uncertainties which arise from these factors.

It appears, then, that not only is current practice oversimplified but that there are difficulties within the methods used which make the results of analyses carried out very uncertain guides to decision making.

DIFFICULTIES WITH THEORETICAL DEVELOPMENT

Difficulties, like the problem of taking account of capital rationing realistically, of the unsatisfactory nature of the prospective or internal rate of return for ordering priorities, and the question-begging of some of the underlying notions of welfare economics which are used, are general economic problems which we will not approach here.

There are still many theoretical problems remaining which are peculiar to water-resource systems.

There remain difficulties in finding suitable mathematical models to deal with all types of streamflows. Even with suitable models, optimization by trial from a series of simulation runs of reservoir behaviour is very expensive in computer time if arbitrary decisions are to be avoided. Direct evaluation of reservoir yield at different reliabilities with different reservoir capacities by means of queuing theory is unfortunately impossible in most practical cases.

The evaluation of benefit functions for irrigation water or the determination of irrigation water demand functions is only just having its initial theoretical development as mentioned in the previous section. (From a demand function a benefit function can be obtained). In other terms, what still has to be done is to prepare a production function for water in terms of physical product and then turn it into a function giving benefit in dollars.

The timeliness of irrigation waterings and the extent to which they fall short of meeting full potential evapotranspiration requirements of a given acreage are two of the many dimensions of the necessarily complex production function. Once such a production function were established for various irrigated crops it would be possible to allocate water optimally among crops, to allocate water optimally over time and to allocate water over the best total number of irrigated acres. Until this work is done, really optimal irrigation system design is impossible.

If optimization at this level could be effected, best release rules for reservoirs could be found without much difficulty, although with much computation, and hence best reservoir sizes.

Economists are becoming concerned with the development of predictive models which can be used for projections into the future of the demand for irrigation water, but these are in an early stage of development. Simulation models can be used in a similar way to predict urban and industrial water demand, but they too are at an early stage of development.

CONCLUSION

Only a few of the many aspects of water-resource system design have been touched on here, but it is seen that much progress is still to be made. One worthwhile step to improve design would appear to be the execution of a programme of sensitivity studies to assess the relative importance of errors in different inputs to analyses so that attention may be drawn to needs for improvement in both hydrologic and economic measurement and estimation. The work that is in progress on runoff and streamflow models will help water-resource system design.

Because irrigation is such an important use of water, continued development of the work on a production function for irrigation water is most urgent. Expensive agronomic experiments are called for.

Because the computational load of any analysis can quite easily become burdensome, ingenuity can still be applied to short-cut the brute-force approaches.

Better communication between analysts and designers and political decision-makers could lead to clearer statements of objectives and of their relative importance.

While theoretical developments hold great promise, most immediate benefits would be obtained from narrowing the gap between existing practice and existing theory.

REFERENCES

1. Maass, A. and others, "Design of Water-Resource Systems," Harvard University Press, Cambridge, Massachusetts, 1962.

2. Commonwealth of Australia, Supplement to the Treasury Information Bulletin "Investment Analysis", Commonwealth Treasury, Canberra, July 1966.

THE TONGARIRO POWER PROJECT

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Formal paper not available.

THE DEVELOPMENT OF IRRIGATION IN THE NEW ZEALAND ENVIRONMENT

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INTRODUCTION

As a land area New Zealand is very small - the area of its good agricultural land is even smaller and its area of good quality flat arable land is somewhat minute. Despite this smallness it enjoys a reputation for pastoral farming equal to the highest anywhere. This is frequently attributed to its adequate, well distributed rainfall and temperate climate. There is little doubt that New Zealand enjoys a bountiful water supply. It is not, however, always where it is wanted, when it is wanted in the quantities that are necessary for full agricultural production. To correct this shortcoming irrigation is practiced in a number of areas, notably in Otago and Canterbury and to a small extent in a few other areas. It is the purpose of this paper to put together the progressive development of the various schemes in operation in New Zealand and to deal in some detail with one undertaking, to analyse its costs and its benefits and attempt to gain a better understanding of the total envolvement in developing an irrigation area in New Zealand.

AREAS

In Otago 18 schemes cover 70,386 acres and serve 785 farmers.

In Canterbury 5 schemes cover 184,600 acres and serve 417 farmers.

Proposed extensios in Otago for four additional schemes would cover a further 122,000 acres.

Proposed extensions in Canterbury for ten additional schemes would cover a further 737,050 acres.

At the present time therefore, excluding private irrigation areas, the major schemes in operation cover 253,686 acres and there is some interest in the development of a further 861,050 acres in the Otago/Canterbury land area.

It is difficult to assess the area of land irrigated in private schemes but from the areas irrigated by other than flood methods it would appear that some 70,000-80,000 acres could be involved.

Relating this area to the total area of potentially very high producing land this irrigation area assumes considerable significance.

WATER RESOURCES:

The water for the Canterbury schemes is without exception drawn from a free flow diversion of a river supply. The three major schemes derive their water from the one source, the 1,000 cusec Rangitata Diversion Race. There are no storage dams or pumps.

In Otago most of the water sources have associated dams or lake storage and a number have pumping stations delivering water to them.

Power generation is associated with several schemes in both Otago and Canterbury.

RAINFALL:

Many of the irrigation areas have reasonable rainfalls; in Canterbury the average rainfall and its distribution is sufficient for a well developed dryland farming system. In many of the Otago areas both total amount and distribution are inadequate and production is largely dependent on having irrigation available.

In Otago their rainfalls vary from 13.6 inches to 29.3 inches over the various schemes. The September/April rainfalls range from 9 inches to 21 inches.

In Canterbury rainfalls have varied from 14.13 to 53.28 over the various schemes with averages from 20 inches to 35 inches. The September/April rainfalls range from 10.06 inches to 50.34 inches.

Despite this there are an average of 59 days in the growing year when the Canterbury soils, in the 30 inch rainfall belt are at or below wilting point.

As might be expected the development of irrigation commenced at an earlier date in Otago. Many of the schemes are smaller than in Canterbury and can be developed somewhat more easily as a consequence. Irrigation commenced with the Ida Valley Scheme in 1917; ten schemes were added in the 1920's and two in the 1930's and three in the 1950's and two in the 1960's.

In Canterbury irrigation commenced with the Redcliffs scheme in 1936, the Levels scheme was added in 1937; Ashburton-Lyndhurst in 1944; Mayfield-Hinds in 1948 and its extension to 1959 and Valetta-Tinwald in 1958. The three last schemes are all part of the development of the Rangitata Diversion Race which was constructed in the 1930's.

In order to examine in some detail the progress of an irrigation area I have chosen the schemes served by the Rangitata Diversion Race. From these a fair picture of costs, development rates, production increases, water use, and investment can be obtained. These comprise an area of 166,400 acres. The construction period was from 1930's to 1959. Water was first made available in 1944. It is possible therefore, to consider progress from 30 years from construction and 20 years of "on farm" development.

The capital cost of construction for the total area stands at $4,771,924. Included in this is 46% of the cost of the Diversion Race. The remainder of the R.D.R. costs are domiciled in a reserve account for future schemes and in the Hydro-electric Station. The construction costs on an acreage basis are from $17.00 for the Valetta Scheme to $36.49 for the Ashburton-Lyndhurst scheme. (This scheme bears 36% of the cost of the Diversion Race). The construction cost per acre for the 166,400 acres is $28.67 if one excludes the $2,018,592 remaining in the Diversion Race account.

These are all flood irrigation schemes and the "on farm" rate of development can be measured by the areas borderdyked. Taken in 5 yearly periods progress is as follows:

	Ashburton-Lyndhurst	Mayfield-Hinds	Valetta
1945/46-1950/51	9480	-	-
1951/52-1055/56	5568½	4172	-
1956/57-1960/61	3381½	3559½	4645
1961/62-1965/66	2543	4172	3399+484*
	20943	11902½	8528
to 1967	21501	13780	*prepared privately

This would indicate that in 20 years of development 33.5% of the Ashburton-Lyndhurst area has been borderdyked; in 15 years 16.2% of the Mayfield-Hinds area and in 10 years 47.3% of the Valetta area. The reason for the greater rate of development of Valetta was the participation of the State in land settlement. On 8274 acres of land it is intended to settle 25 farms each with 200 acres of prepared border dykes about two-thirds of the farm area. (As at 1965/66 17 units comprising 5,534 acres was settled).

Most farm development, particularly during the period under review, will have been done out of income. The costs of land preparation are of considerable interest in relation to this type of development. The following sets out the actual costs over the years: (Per acre costs in five yearly averages).

	Ashburton-Lyndhurst	Mayfield-Hinds	Valetta
1945/46-1950/51	$ 5.79	$ 7.82	
1955/56	$ 8.14	$ 8.70	
1960/61	$11.56	$11.60	$13.03
1965/66	$10.84	$12.62	$14.65

There are probably two factors operated in these fluctuations. Firstly, overall increases in costs of machinery, maintenance and wages, and secondly, the tendency to prepare the slightly easier areas first. Valetta is more costly than Mayfield-Hinds and Mayfield-Hinds more costly than Ashburton-Lyndhurst and this is a true reflection of the topography and slopes of the areas concerned. Other items which now have to be considered are the costs of reborder-ing, the costs involved for better type race construction and land preparation required for automation and changes in layouts. The 1966/67 figures can be used to give some indication of these. The average cost of normal borderdyking for 2053 acres done that year was $16.72. For 1142 acres rebordered $10.80, and this would involve considerable costs for automatic races. Where layouts requiring a change of angle were involved costs of rebordering were almost the same as for new bordering $16.23 (for 312 acres).

I feel certain there is considerable misapprehension among farmers not practising irrigation as to the actual commitments of the farmer with regard to land preparation. They see this development proceeding with large machines and a number of groundsmen, they see huge masses of soil being shifted and earthworks for race lines being constructed and they finally see an altered landscape over which water can be evenly flooded. This represents a lot of work and I am sure it appears more costly than it actually is. The figures presented above represent more than full recovery for the work actually done on the three schemes involved for the 20 year period under review. There are areas where costs will be greater than above and some of these are now under consideration for development.

The farmer is involved in a number of costs after the land has been prepared and the races cut. This item has been quite variable depending on the degree of control and the reduction of effort required by the farmer. Costs vary from about $2 per acre to $10 or $12 per acre. Where the farmer required good control a cost of about $8 an acre would be involved.

The most significant change from the conventional development over the first 20 years to that in operation at the present time is the involvement in automation. This system requires additional "in race" structures but eliminates the use of headgate boards and replaces the headgate blocks and concrete sill with a treated timber sill. The races are generally higher and a little larger.

Where systems are designed to accept these changes on new areas being prepared it would cost an additional $1 for race construction, from $2 to $5 for in race structure and the treated wooden sills would cancel out the head gate blocks.

Where previously installed manual systems require conversion for automation costs will vary depending on the degree of sub-division and the amount of pre-planning applied to the previous layout. It is expected that these alterations will be expensive and may involve costs not much less than the original expenditure. These facts are borne out in the costs presented for 1966/67 where re-bordering costs ranged from $10.80 to $16.23 per acre.

The most important factors related to the amount of water used are: the rainfall and its distribution; the area of land prepared for controlled flooding; the requirement for pasture related to the stocking rate and the labour involvement. There is an obvious inter-action between the area prepared and the stocking rate so that as stock numbers rise the commitment to irrigate becomes greater despite the type of season. This trend is well borne out by the increasing use of water in the Mid-Canterbury schemes.

Water Used (acre ft) Yearly Average

	Ashburton-Lyndhurst	Mayfield-Hinds	Valetta
1945/46-1950/51	7,500 (25.99)*	1,094 (31,03)	
1955/56	25,803 (24.91)	8,303 (25.35)	
1960/61	28,150 (25.00)	14,061 (23.52)	7,012 (23.4)
1965/66	42,637 (23.98)	23,464 (25.49)	19,140 (26.19)

*The 5 year average September-April rainfall is shown in parenthesis.

Too much weight should not be given to these short-term averages but they do suggest that despite similar average rainfalls water use is steadily increasing as the areas prepared for irrigation increases. For instance in the Ashburton/Lyndhurst scheme record water use of 61,542 acre feet was established in 1963/64 when the September/April rainfall was 22.12" whereas with the lowest September/April rainfall recorded in the period under review (1955/56) of 17.20" only 44,580 acre feet were used. Similar trends to this are shown on all schemes.

Where operation revenue is collected from water sales it is obvious there will be fluctuations from year to year and also obvious that revenue will steadily rise as the prepared area increases within the irrigation scheme.

The upward tendency for water use in the last five year period is not a reflection of increasing dry years but is due to the introduction of automatic irrigation which has increased the use of night irrigation and also increased the area irrigation per acre/foot of water delivered.

There are three great benefits to be derived from the introduction of automatic irrigation to schemes such as those in Canterbury based on a continuous free flow diversion of water.

It permits water to be used for the full 24 hour day. It allows unattended night irrigation.

It doubles the efficiency with which water is used. This is an indirect effect resulting from the increased accuracy of water use and water changing intervals.

It reduces the labour content for a controlled flood system of irrigation to negligible proportions. Where schemes are provided with an 8 cusec flow the aim should be to irrigate 1 acre of land for each minute of labour applied to distributing water on the farm.

The development of irrigation is governed by several factors and it must be realised that it is not possible to change a dryland area into an irrigation area overnight. It would seem reasonable to assume from the progress of the various schemes in Canterbury that the construction period for a major scheme might be of the order of ten years and that an average rate of development might be of the order of 2% of the area commanded per year.

If we consider the development of the five schemes in Canterbury covering 184,600 acres a small area of which was first served with water in 1937 we can summarise the development since then by saying that by 1966 33.5% of Ashburton-Lyndhursts 64,000 acres has been borderdyked, 16.2% of Mayfield-Hinds 85,000 acres; 15.2% of Levels Plains 12,800; 25% of Redcliffs 5,400 acres; 47.3% of Valettas 17,400 acres; or 24.8% of the total 184,600 acres has been fully developed to date. This gives 45,811 acres of fully developed land in about 30 years. Only a small area of this (19,200 acres) was available for development in the first 10 years. The majority of the land has been developed out of income and this rate of development should be considered as being comparable with most development enterprises which are undertaken out of income.

The rate of development and the subsequent state of development is dependent on many different factors in different irrigation areas. Some of the factors are:

Irrigation need

Water availability

Size of farm

Available finance

Available labour

Points that illustrate this are for example: Where irrigation need is great as in the low rainfall areas in Central and North Otago and in South Canterbury initial development can be quite rapid. In Otago schemes such as Upper Waitaki and Pisa Flat reach $\frac{1}{3}$ development in the first few years. Where soils are droughty despite good rainfall early development is good. Valetta, with quite high rainfall developed at a fast rate in the early years. This was not solely a factor of State investment as there was no difference between the State and private settlers in the first years of development. In the first year 1958/59 both had developed 14% of their areas whereas this had not been reached until the seventh year for Ashburton/Lyndhurst and not until the seventeenth at Mayfield-Hinds.

At Redcliffs, where irrigation need is great, more water was used in the second year of development (1937/38) than for any other year in the period under review up to 1965/66. However, in the 1966/67 year a new record for water use was established as a consequence of a series of droughts, the introduction of automation and the improvements in techniques of land preparation and an improved water supply. The reason for the fall away, from initial enthusiasm to apathy was unreliable water availability.

The Levels Plains scheme also illustrates the restriction to development imposed by an unsatisfactory water availability. Its development to 15.2% is solely due to the impossibility of developing a farming system based on high year round stocking rates when water becomes unavailable during the driest part of the year. This restriction also applies to some of the Central Otago schemes.

Where properties are large such as throughout Mayfield-Hinds, they are fully economic, and considered high producing in the farmer sense without irrigation. Irrigation tends to be used as an insurance in dry years to provide for the maximum dryland stocking rates of wet years. This means that partial irrigation is a very valuable asset in a situation where production can vary as much as 300% between a wet and a dry year. (This is the extent of variation measured on the dryland areas at Winchmore between good and bad seasons). Another very obvious factor retarding the extent of development on very large properties in the past has been the extent to which one man could handle a manual system of flood irrigation. Mayfield-Hinds has therefore developed to 16.2% of its area to date.

An irrigation undertaking within the farm is not inexpensive. It requires a good deal of finance and indeed is possibly the only agricultural undertaking where the finance has to be available before the job will commence. Under the system operated in New Zealand (up to the present time) the job cost is estimated and the farmer has to pay this to the public account before the contract is started. Adjustments up or down are made after completion. Thus to develop out of income the farmer must have hand cash available. Where the State has played a part in development the ultimate rate tends to be better as instanced by schemes such as Ashburton/Lyndhurst, Valetta and Pisa Flats.

The extent of development is often governed by the labour available. This would be a major feature in restricting the use of irrigation where a continuous water flow is used. In such cases a roster must be used and water is available for 24 hours a day. Manual night watering is justifiably unpopular. Sunday and holiday watering, watering at harvest and at shearing and at other peak periods of work on the farm (such as the opening of the fishing season) also set a limit to labour availability. It is to be hoped that the introduction of the present practical system of automatic flood irrigation will eventually do much to remove this major restriction to irrigation development on a farm. Farmer opinion sets the labour limit of irrigation to about 200 acres for a one-man unit under a manual system of irrigation. The area could be increased to 800-1000 acres or perhaps more under an automated system. It is for this reason that all new developments are incorporating automation in their layouts. (The problems of conversion of the existing units has already been mentioned.) Not only will automation reduce the labour of water distribution to a very low level but it will also improve quite substantially the area irrigated per available cusec.

From a national viewpoint the investment in irrigation in Canterbury is very small. At the present time this stands at $5,026,012 of which surprisingly little came from the Employment Promotion Fund, $258,786. This investment represents an "off farm" expenditure of $27.22 per acre on an irrigation area of 184,600 acres.

Full development has taken place on just a quarter of the area. In the original concept for irrigation in Canterbury it was envisaged that only 50% of the area would be irrigated.

It is interesting to relate this degree of development to the increased productivity and to the potentials as a measure of progress. There is very little information in this field but what there is appears to fit a very logical pattern.

In assessing farmer profitability within the Ashburton/Lyndhurst area, Stewart (The Comparative Profitability and Productivity of a Sample of Irrigated and Non-irrigated Farms in the Ashburton-Lyndhurst Area, June 1963) was able to show that, on a comparable area of irrigated land compared with its counterpart, unirrigated, the value of gross output had increased by 50%. This figure was devised up to 1962 and further increases have followed since then. However, development within the area surveyed had reached a little over 50% so that the area surveyed would be ahead of the average for Ashburton-Lyndhurst at that time. The relative figures from this report are:

	Irrigated		Dry	
Number of farms	17		9	
Total area (acres)	6,770		6,754	
Area of Cash Crops	247		658	
Area of Small Seeds	14		70	
Number of Breeding Ewes	20,851		12,748	
Other Sheep	6,798		2,241	
Cattle	434		151	
Animal Units		26,651		14,734
Gross Output	$209,098		$141,794	
Gross Output/acre	$ 30.60		$ 20.50	

Productive studies at Winchmore Research Station have shown that the potentials under full irrigation are 100% higher than under dryland conditions. These two figures show remarkable agreement.

The returns from animal products on a fully irrigated unit can be high and can be sustained for very long periods. From the period 1952 to 1966 the gross income from an irrigated sheep unit at Winchmore has averaged $69.14 per acre. This has ranged from $53.99 to $96.20. It has not been possible to allow for rent, interest, wages of management or on farm labour costs. But direct costs of fertiliser, irrigation and stock replacement have averaged $13.75 per acre. This shows a gross margin of $55.39 from an irrigated sheep enterprise, which allows a fair margin for labour and internal costs of operation.

The average water used has been 2.9 acre feet. This has cost an average of 69c per acre.

On the 297 acre property of Mr. G. B. Henderson at Lyndhurst (32" average rainfall) a gross income of $90 per acre was obtained in 1966. All but 14 acres of this property can be irrigated. Mr. Henderson in 1964/65 carried almost 7 sheep to the acre on the area under grazing. This compared with 2.9 and 2.5 sheep for the 1951/52 and 1952/53 seasons. Since these years wool production has risen from 42.3lbs to 80lbs and meat production from 125.8 to between 237.2 and 260lbs in the seasons 1962-62 to 1964-65. This enterprise includes crops of wheat, barley, peas, linseed and white clover seed, somewhere round 100 acres being harvested. This accounts for the high gross return.

These examples substantiate the potentials of full irrigation with existing techniques. They could well be confirmed by the figures produced in the table above where a 50% improvement in gross output is shown with 50% development.

It is not possible to give an exact estimate of the value of this increased return but it can be estimated.

At half potential development the increased gross return of $10.10 per acre means there is a substantial national gain from the investment $5,000,000 on 184,600 acres, over 36%. This gain is largely in overseas earnings. This should institute a good case for increased Government activity in expanding the use of irrigation in the lower rainfall areas of New Zealand.

The purpose of this paper was to examine the development of irrigation in a situation where normal farming practices are economic and productive in its absence.

The majority of the development has been done by private enterprise without State assistance and has therefore been largely financed out of income. Inflationary pressures and finance are the factors most likely to influence development under these conditions, and the rate achieved of about 2% per year is almost certainly about the level one would expect under these circumstances.

It is obvious that a much faster rate of development would have many encouraging features. It would return the Government an even greater reward in increased production and with the more rapid development the return from water sales would more rapidly meet the operation and maintenance costs. Costs of operating and maintaining the Canterbury schemes are not high. Excluding interest on capital and considering the gross operation and maintenance costs over the last five year period up to 1966 these have amounted to:-

	Ashburton-Lyndhurst	Mayfield-Hinds	Valetta	Levels Plains	Redcliffs	Total
Yearly average 5 years to 1966 (includes R.D.R.)	\$40,614	\$27,270	\$13,466	\$12,695	\$5,836	\$99,782
Average per acre: Gross area	63c	32c	77c	99c	\$1.08	53c

The Government could well do more to stimulate development so that increased sales of water could meet these moderate charges. In 1953 and again in 1959 recommendations which could have assisted in this direction were placed before the Government and these have largely been ignored.

No attempt has been made in this paper to present the many encouraging features associated with irrigation farming in low rainfall areas but these are obvious and many.

I have culled a few remarks from a publication dated 5th September 1939 to show that we have progressed a long way (I hope) since then:

Quote -

(1) Irrigation will sour the land and in the course of time spoil its fertility, especially if it is to be ploughed again.

(2) The lands below those irrigated will be constantly flooded.

(3) Nothing can be grown but grass, and crops such as wheat, on which Ashburton's prosperity in the past has rested, will disappear.

(4) Even if grasses are shown to be permanent, it is almost certain that old grass will lose its palatability.....

(5) The watering will give large quantities of feed in Summer, but none in Winter, which is after all the factor that limits capacity.

(6) The races would scatter weeds over the land...and that gorse seeds will be carried wholesale onto the fields, again necessitating ploughing and destruction of the checks.

(7) The Winter feed position is now largely dominated by Porina, Grass Grub, Diamond Back Moth, Aphis and (last year) White Butterfly. It is probable that all these will thrive the better if they have looser and moister soil to work through and more luscious leaves to eat.

(8) Half bred sheep will no longer be able to be used. They are the only kind whose management the Ashburton farmers understand.....

(9) If it is suggested that cattle should be carried then the cattle would poach the land after it was watered.

(10) New and unsuspected diseases will break out.

Unqoute.

We are still not free from the emotions which generated these (few of many) remarks. But it is a good point in time to examine their truth. Just on thirty years of progress would not substantiate any of these dire predictions. In fact, the opposite has happened. In the year just past Ashburton has possibly its record wheat harvest, the drylands have been ravaged by pests, half bred sheep are almost a rarity and cattle are seen in considerable numbers grazing on old irrigated pastures which do not appear to have lost palatability and certainly there is no sign of a gorse invaded plain, or flooded lowlands.

Irrigation has proven a pretty good investment for both the State and the farmer and deserves to receive some encouragement from both, certainly more than it does from either at this time.

I wish to acknowledge the assistance of the Ministry of Works in providing information from their various reports which has been used in this paper.

ECONOMIC EVALUATION OF WATER RESOURCES DEVELOPMENT

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INTRODUCTION

An impressive array of literature dealing with water resources development is accumulating in the bookshelves of both economists and engineers. This literature stresses the essential interdisciplinary teamwork involved in the study of water resources - teamwork involving primarily the economist and the engineer, with recourse to the advice of the geologist, soil scientist, plant scientist and other professions. It has become professionally respectable, even fashionable to call for a higher degree of interdisciplinary co-operation between the economist and the engineer; it seems to me that as both professions proceed to a higher degree of internal specialisation that the exhortation to the economist and the engineer to find common ground in the field of water resources development may be lip service to an ideal which few really expect to achieve.

The engineer describes his discipline as "the art of directing the great sources of power in nature for the use and convenience of man" (42) and as "the art of organising men and of directing and controlling the forces and materials of nature for the benefit of the human race". While a definition of any discipline is a notoriously inadequate description, I trust it is not suggested that the engineer is favoured with prior knowledge of what constitutes a benefit or a convenience to the human race.[1] More modestly, but just as idealistically, the economist would probably agree to a definition of his discipline as "the study of how how men and society choose, with or without the use of money, to employ scarce productive resources to produce various commodities over time and distribute them for consumption, now and in the future, among various people and groups in society" (37). The basic tenet of the economist is the acceptance of consumer sovereignty and the implication that the market should demonstrate in the long run what men and society regard as beneficial to themselves. Further the economist would suggest that both social and economic forces, acting through the political machine should ideally dictate the scope and direction of the engineer's activities. It is regrettable that these two professions (and many others) apparently dedicated to the well-being of mankind often exert social or political pressures in different directions, and baulk at the suggestion of mutual assistance. The interests of society could be better served when two professions with similar goals and overlapping fields of interest act in concert, and pull in the same direction.

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1 The effectiveness of the power lobby in New Zealand and the irrigation lobby in Australia suggests that some engineers have "prior knowledge" of what society wants and needs.

Most modern political machines are charged by society with the responsibility for:

(a) Maintaining full employment - by creating conditions in the economy, by various means, whereby the demand for labour continues to grow at the same rate as the labour force increases.

(b) Promoting a satisfactory rate of economic growth by creating an environment which encourages the establishment and expansion of industries, and providing services such as education, research, power and extension etc.

(c) Maintaining a reasonable stability of prices by ensuring that the ability of the population to spend increases at about the same rate as the goods and services available.

To some extent, these aims are not fully compatible; successive New Zealand governments have accepted and to some extent fostered, a social demand for ranking the aims as above. Full employment has been maintained by a high level of protection to industry, and a high level of government activity. Governments of other developed countries are more likely to rank (b) or (c) as the primary social aim.

Irrespective of the ranking of domestic policy objectives pursued by government, the role of government expenditure deserves close attention in the preamble to a paper of this nature. Traditionally, governments inject huge amounts of money into circulation in both capital and current expenditures. This money serves several purposes, the more important of which are: <u>first</u> the provision of essential goods and services (e.g. water resource development, education, defence, justice and so on) which may not be provided by private firms for one reason or another, but which are deemed to be desirable by society; <u>second</u> to provide a stimulus to the general economy, to achieve a desirable and balanced growth rate. The level and direction of government expenditure is quite important and ideally should be capable of variation as a countercyclical weapon to dampen the amplitude of the business cycle. In general terms, the economist is capable of advising government of the desirable <u>level</u> of government expenditure in a given economic situation. However advice regarding the desirable <u>direction</u> and destination of government expenditure is more difficult to provide.

In the private sector of the economy, economists generally accept the premise that the price mechanism, if not interferred with in an undesirable fashion, will distribute resources in a more or less optimal manner. However in the public sector, which includes most water resource developments, the price mechanism may malfunction, may break down completely, or distort consumers' preferences. It is therefore the responsibility of the economist to evaluate the social benefit attainable from various avenues of government expenditure, and to suggest how this expenditure could be disseminated to achieve the maximum social benefit. This is a tall order. No economist would suggest that this is yet possible in other than theoretical models. The techniques frequently used in the economic evaluation of water resources are in fact clumsy, (but we hope not too inaccurate) attempts to measure the "social worthwhileness" of a project - the return to society following a given public investment.

To summarise at this point we have to recognise firstly that the desirable total amount of government expenditure and consequently the extent of public works is dictated by social, political and economic objectives, and secondly that government expenditure should be channelled into the most socially productive avenues, whether or not this includes large-scale water resources development.

THEORETICAL BACKGROUND

There will be no need to derive conditions for optimum allocation of water resources in this paper. Economists will be familiar with these conditions, others interested in economic evaluation of water resources development will have been exposed to them at some stage. The conditions have been described in several texts and papers (e.g. 4,14,7). In its simplest form economic theory states that units of a resource are optimally allocated among alternative uses, and a state of equilibrium exists, when the value of the marginal product is equal in all alternative uses. i.e.

$$MVP_{xy_1} = MVP_{xy_2} = \ldots\ldots = MVP_{xy_i} = \ldots\ldots = MVP_{xy_n}$$

where MVP_{xy_i} = the value of the (social) marginal product of resource x in use y_i.

In the context of the public sector, $y_i \ldots\ldots y_n$ would represent the various avenues of government expenditure, of which one would be water resources development. Ideally then the allocation of funds to development of water resources would be such that the (social) benefit gained from the last dollar in this use is equal to the (social) benefit of the last dollar in other uses. It would be naive to suggest that the socio-political-economic framework within which government operates has achieved such an optimum allocation of funds - although we as economists are frankly not in a position to do more than protest at what we feel to be gross misallocation of government expenditure.

In the context of water resources, the $y_1 \ldots\ldots y_n$ would represent the various alternative uses of funds in water resource development e.g. different combinations of hydroelectricity generation, irrigation, flood control, recreational use, etc., which are technically possible. The (optimum) amount of funds allocated to water resources development will be optimally allocated between alternative water resource uses when the (social) benefit gained from the last dollar in each alternative use adopted is equal.

The foregoing discussion outlines the ideal allocation of resources from the point of view of the economy generally. We shall consider briefly now the objectives of water resource development and their relationship to the economic optima outlined above.

In recent years the level of interdisciplinary co-operation in theoretical watershed planning has reached an impressive level in the United States. This is exemplified by the several texts (e.g. 31,41) and papers available. Little has been achieved at the practical level, particularly in Australia and New Zealand. The econo-engineering approach to economic allocation is micro-economic, considering as a rule the optimum planning and development of a given watershed, or set of physical resources, assuming that sufficient capital is available for a feasible development programme. An elaborate, logical theoretical foundation, and the use of computers has taken watershed planning from the sphere of guestimates to the world of informed analysis.

However, optimisation within the conceptual unit of the watershed does not necessarily imply, or even suggest optimisation within the macro-economic (or whole economy) framework outlined above. The prime objective of water resource development is often stated as the maximisation of national welfare (32). Marglin (p.18) neatly side-steps the macro-economic approach by stating - "in view of the three-dimensional nature of national welfare - the size of the economic pie, its division, and the method of slicing - we believe it unwise to attempt a single index for this broad objective; instead we shall develop alternative objectives for the most important ways in which water resource development can contribute to national welfare". These objectives are firstly <u>efficiency</u>, defined as a type of net social benefit function, and secondly desirable <u>income redistribution</u>. Marglin specifically assumes perfect competition and equilibrium throughout the general economy. Ciriacy - Wantrup (8) recognises the apparent incompatibility of traditional watershed policy objectives with optimising social welfare by equating the MVP's of resources in alternative uses. He describes these optimisation criteria as "constructs in the sense of useful scientific fictions" - "optimisation is not and cannot be an actual policy objective", and further that "the actual objective of policy decisions involves successive incremental improvements of the existing state of welfare, considering a limited number of alternatives". He suggests that for policy decisions of a limited scope, e.g. evaluating individual watersheds, that these incremental improvements in social welfare can be determined cardinally. These statements imply that we should head for the optimum we can see, that of the individual watershed, and hope that the general optimum is in the same direction.

In summary, the optimum water resource development plan is in a sense a sub-, local, or mini-optimum in that it relates to a restricted area of the economy. Heading for this optimum may (we hope it will) or may not lead us in the general direction of the optimum allocation of government expenditure. No suggestion has been made that the state of the arts makes precise definition of this latter optimum possible. [2]

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[2] Musgrave (35) has reminded us of the limitations of the use of objective efficiency criteria in one sector of public expenditure, by drawing attention again to the theory of the Second Best. Described in (29,33), this theory in our context illustrates that insistence on efficiency conditions in water resources development and not in other fields e.g. government transport etc., could lead to a worsening of general economic efficiency.

Irrespective of the general arguments above, related to general optimal and sub-optima, the evolution of water resource planning from a "minimum cost for a given project" to a "planning projects for maximum national welfare" approach is a necessary and significant contribution to the efficient use of national resources.

TERMINOLOGY

This paper will avoid tedious descriptions and definitions of the commonly used terms in water resources development and simply summarise some definitions thought appropriate for use in project evaluation in New Zealand. [3]

Benefits are increases or gains in the value of goods and services which result from investment. They are usually measured net of associated or indirect costs, and may be tangible (able to be expressed satisfactorily in money terms) or intangible (not fully measurable in money terms). Direct (or Primary) Benefits arise directly from the investment, and in the study of water resources development could include benefits from improved water supply and quality, irrigation, navigation, power, flood control, land stabilisation, drainage, recreational uses etc. Direct benefits are measured net of the direct costs of construction and operation of the project and of the costs of making the products or services available for use or sale.

Secondary (or Indirect) benefits measured net of non-project costs are the increases in the value of goods and services which result indirectly from the project, such as increased incomes of businesses affected by the particular investment. It is probably tidier to refer to secondary benefits when assessing schemes from a local or regional viewpoint and incorporate them into spillover effects when the national viewpoint is taken. These secondary and spillover effects, concerning the population not directly concerned with the project are labelled externalities. The distinction between direct and indirect benefits is an artificial one when a project is considered from the national viewpoint (38).

ECONOMIC EVALUATION PROCEDURES

Rapid development has occurred in recent years in sophisticated techniques for measuring benefits and costs associated with water resources development, and of techniques for river basin planning. An important and fundamental distinction should be made at this stage between techniques designed to evaluate given projects by assessing the net benefits expected to accrue, and planning techniques, designed to provide an optimum water resources development or operational plan for given projects, combination of projects, or for a total watershed.

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[3] Terminology was the subject of one of several papers delivered to a seminar on Project Evaluation in New Zealand at Lincoln College (24) during November 1967.

It is possible to distinguish five levels at which techniques of evaluation and planning might be applied in the study of water resources:

<u>Level 1</u> the single-structure level, e.g. the construction of a reservoir for irrigation or power generation. The study is limited to the immediate project and does not include interactions with other areas or structures in the same watershed.

<u>Level 2</u> the multi-structure level, e.g. the consideration of several structures in a watershed. A study of this type would include interactions between structures and areas in the same watershed, and would be concerned primarily with some optimum combination of structures or optimum operating procedures.

<u>Level 3</u> the watershed level, where an attempt is made to integrate all structures, existing and proposed into a watershed model.

<u>Level 4</u> the national water resources model which would attempt to integrate the characteristics of some or all watersheds in the country or state into a national planning model.

<u>Level 5</u> the national public expenditure model which would attempt to include water resources development into a model representing all avenues of government expenditure.

For many years, evaluation and/or planning techniques were applied only at level 1. Indeed it is still true to say that many single-structure projects proceed to the construction stage without adequate evaluation. It might appear at first sight that <u>level 1</u> studies should be straightforward and fairly simple. Experience has shown however that the evaluation and/or planning of even a single structure is a highly complex procedure. Uncertainty is the biggest problem facing evaluators or planners; uncertainty in hydrological data, future prices, and costs, is a fact of life but often makes both planning and evaluation uncomfortably subjective in practice. Often the only alternative is the maximisation of the expected value (in the statistical sense) of net benefits, or the production of an "optimal" design of a system for a given project.

As techniques have been developed to cope with <u>level 2</u> and <u>level 3</u> studies, they necessarily abstract from reality to a large extent because of the sheer size of the problem and the impossibility of including the multitude of known variables in one computer model. Computers available are often not large enough to handle these complex models. This increasing over-simplification often reduces the nature of the model to a simplistic representation of reality and consequently reduces the value of the conclusions which can be drawn. To my knowledge, substantial models have yet to be developed at <u>level 4</u> and <u>level 5</u>.

The term benefit-cost analysis has two quite distinct meanings in the literature - first, as a discounting technique within the framework of project evaluation [4] and secondly a broader interpretation [5] including all techniques which are designed to measure the direct and indirect

[4] See author's paper in (24)

[5] See Stoevenor & Castle (38), p.579

benefits throughout the economy. The term is used here in the former sense.

Techniques applicable to water resources development are of three rather loose categories:

(a) Discounted flow techniques.
(b) Analytical techniques.
(c) Simulation techniques.

These will be briefly discussed in turn.

Discounted flow techniques

These techniques rely on the specification of an expected stream of future benefits and costs associated with a given project, applying an appropriate discount factor, and expressing net benefits in terms of a present value. Monetary terms are used as the most satisfactory common denominator of value. The approach is essentially static, and the effect of time is introduced through the discount rate.

Benefit-cost analysis, as a sub-set of discounting techniques is distinguished from discounted cash flow techniques by the fact that "it specifically takes externalities into account, and by so doing, encompasses a wider viewpoint than other forms of project evaluation carried out from the more restricted viewpoint of an individual firm, a public corporation or even a government department wedded to a conventional notion of profitability". (44)

It is difficult to locate "true" benefit-cost studies in water resources development. Examples of assessment of primary benefits from irrigation water in the United States are available both from ex ante (9) and ex post (1, 27) studies. Johnson (25) has provided an extensive review and bibliography of irrigation, water supply and drainage studies in New Zealand, none of which have attempted to estimate secondary benefits.

Estimates of expected future direct benefits from water resources development will often involve detailed and painstaking collation of benefits accruing from several sources. However, once certain assumptions are made regarding future prices and so on, the estimation of direct benefits, especially in the case of irrigation and drainage projects, becomes an exercise in detail rather than a problem of conceptual difficulty. The same is not true of the estimation of external effects. If a project is to be evaluated from the comprehensive public viewpoint, the effect of establishment of this particular project should be traced as far as possible throughout the economy. This means each avenue of economic activity affected by a project must be probed for the extent of its probable reaction. Several approaches are possible to the measurement of externalities; some brief examples will be given, others are available from the literature. Brown et al., (3) used the Clawson method [6] of deriving a demand curve for recreational fishing,

[6] The demand schedule is measured by plotting the estimated costs per visit as a function of the number of visits to a fishing area, per 100,000 population in a zone in a given distance range.

enabling acceptable estimates of the effect of alteration of fishing facilities. A detailed method for quantification of road-user savings has been developed (12). The impact of an irrigation project on local employment, population levels and retail sales have been measured by Kimball and Castle (28) in both absolute and elasticity terms.

Discounted flow techniques, being both static and partial have to be used with imagination if they are to contribute in any sense to an optimum allocation of resources. They normally concentrate on one project, of a given size and seldom made inter-area interdependencies clear. They will provide an indication of the contribution of the investment to income - national, regional or individual, depending on the viewpoint taken. For preference, if time and funds permit, several distinct project sizes should be evaluated to obtain an optimum scale of investment. [7]

The growing insistence by international lending institutions and governments for economic justification of large scale expenditure of public funds has seen an upsurge in recent years in interest in benefit-cost analysis. As administrators become more enlightened we can expect these demands to increase. While theoretical discussions continue in professional journals, a growing number of "economic evaluators" are grasping discounted flow techniques with both hands, and applying them to a wider range of minor water-resources problems.

Analytical Techniques

This group of techniques is based on the construction of a mathematical model to represent the reality of interactions and interdependencies which occur in all but the very simple water-resource development situations. The mathematical model is a set of equations to be solved by standard methods of calculus or some type of activity analysis, usually to obtain optimum values of the design variables. These variables could be reservoir capacity, power-generating capacity, recreational use, flood control and so on. These techniques are essentially aids to design, although some have been effectively applied in evaluation studies.

As techniques used in water resources development have increased in sophistication (and therefore become more professionally attractive!) and precision (an aura of infallibility surrounds such models), a hunger for data develops. Hydrological and economic data share the common property of scarcity in volume and uncertainty of value from which is is comforting to escape behind the shield of simplifying assumptions. As time progresses and the use of analytical and simulation techniques becomes more common-place the paucity of data will doubtless become the limiting factor in both evaluation and planning techniques. Both the inadequacy of data and the limitations of computer space are important reasons why analytical models are usually restricted in size, and therefore are less informative. Most models developed portray only a part of a watershed, or one or more of a river's important features, or are quite over-simplified models of a watershed.

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[7] See p.13, of the "green Book" (43), for the simple theoretical basis of scale of development.

Linear Programming as a technique has been in common use in various professions for many years. In general terms the technique involves the maximisation (or minimisation) of a linear function of choice variables - the objective function - subject to restraints. These restraints are either equalities or inequalities involving linear functions of the choice variables. The choice variables are the numbers which are to be chosen in the maximisation process e.g. reservoir capacity, irrigation use and so on. The simple maximisation problem can be represented thus; with reference to a profit maximisation problem:

$$\text{Max } Z \text{ (profit)} = c_1x_1 + \ldots\ldots\ldots\ldots + c_nx_n \quad \text{(objective function)}$$

subject to:

$$a_{11}x_1 + \ldots\ldots\ldots\ldots + a_{1n}x_n \leqslant b_1 \quad \text{(resource restraints)}$$

$$a_{21}x_1 + \ldots\ldots\ldots\ldots + a_{2n}x_n \leqslant b_2$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$a_{m1}x_1 + \ldots\ldots\ldots\ldots + a_{mn}x_n \leqslant b_m$$

and

$$x_1 \geqslant 0 \ldots\ldots\ldots\ldots\ldots x_n \geqslant 0 \quad \text{(non-negativity restraint)}$$

where
c_i = "profit" from ith product
x_i = amount of ith product or activity
b_i = supply of ith resource
a_{ij} = input-output coefficient - each unit of the jth activity requiring 'a' of the ith resource.

Two brief points regarding this technique should be made. First, if a (watershed) situation can be described adequately by a linear-programming model then for the maximisation of profits the number of activities used would not exceed the number of restrictions limiting operations; second, no activity will be excluded from an optimal operating programme which is more profitable than its equivalent combination included in the programme. Taken together these points [8] are the "linear programming analog of the equate your marginal productivities dictum in orthodox marginal analysis", summarised earlier in this paper. There is conceptually no real difference between maximisation and minimisation in linear programming.

Once the flexibility of linear programming is recognised, it can be readily recognised that many water resources development situations can be studied in a linear-programming framework. Castle [9] explains the use of linear-programming in these situations:

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8 Outlined as theorems in (13).

9 Ch. 12 in (41).

(a) the maximisation of annual net benefits from three proposed reservoirs for either supplemental or full irrigation of four alternative areas. The restraints are limits on individual reservoir capacities, dictated by watershed yields and topography, and on total reservoir capacity.

(b) the maximisation of annual net benefits from two reservoirs supplying irrigation water for two crops. Each reservoir is subject to different rainfall and runoff characteristics, from which the restraints are derived. This example illustrates the optimum use of interdependent structures.

(c) the maximisation of benefits by allocation of water among alternative uses - irrigation and power generation. Castle and Lindeborg (7) have applied linear-programming to the problem of ground water allocation between districts and crops to maximise yearly net returns from irrigation. The use of linear programming for optimal operating policies has been adequately outlined in theoretical terms (40).

A particularly interesting study by Pavelis (36) combines conventional benefit-cost analysis and linear programming. The objective function was maximisation of discounted benefits from land treatment and structural measures in the development of a watershed. Benefit-cost analysis was used as a "screening device" to eliminate land treatment measures or water structures which did not provide positive discounted net benefits. Linear programming was used to obtain the optimal combination of land treatment and structures found to be "desirable". A solution consistent with resource availability is obtained conventional benefit-cost studies would need to be used with unprecedented imagination to achieve this end in a multi-structure, multi-purpose study. A similar programming model, without an empirical example has been provided in detail by Heady (21).

One of the important by-products of linear programming is the provision of "shadow prices" or MVP's of the scarce resources. These are useful in the valuation of water resources, as well as optimal allocation problems. Production function analysis provides probably the only alternative method of obtaining MVP's.[10]

The development of dynamic programming has not contributed substantially at an operational level in the field of water resources. Dynamic programming techniques allow the construction of sequential decision models, where optimisation is done in steps. The application of this technique has been restricted by computational difficulties and the limitations on the memory space of available computers.

Theoretical models have been developed for minimum operating costs (40), intertemporal resource allocation (4) optimising the development of water resources, (16, 17), the optimal design of aqueduct capacity (15), optimisation of reservoir design, design of flood control reservoirs(5), and so on. Probably the only study of a practical nature

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10 See (34).

is Little's (30) model for determining the optimal water storage policy for an electricity generating system.

Input-output models have entered on the fringe of the evaluation of water resources development. These models are essentially sets of equations representing production activities which have been empirically determined. They are not normative models in the sense that optimisation criteria are applied, but are general empirical models of production representing an economic entity (nation, watershed etc.). They stress the interdependence of the various production processes.

Their impact in water resources development has so far been felt mainly in the estimation of the level and distribution of secondary benefits. We have already seen (3, 12, 28), that secondary benefits can be usefully measured by other techniques. The value of the input-output model lies in its "ability to portray the flow of goods and services throughout an economy and may be the only possible way to take into account all relevant changes in output which may give rise to secondary benefits" (38). From the point of view of economic evaluation of a given project however, our interest lies only in the magnitude of secondary benefits, and it has yet to be shown that the time and funds necessary to construct input-output models is justified by providing significantly better estimates of the level of secondary benefits. There can be no question however that the coefficients of the input-output model would provide most useful information if the distribution of secondary benefits in the form of changes in incomes of individual sectors is required.

Examples of the use of Input-Output models are not plentiful. The magnitude and distribution of benefits from controlling water pollution in a sports-fishing area have been measured in this manner for a small area (39). Kalter (26), has produced an extremely valuable study using input-output analysis in estimating local secondary impacts of water based recreation investments, deriving short-run and long-run multipliers.

Simulation Techniques

Simulation is not new- although as far as I know it is yet to make its debut in the field of evaluation of water resources development in either Australia or New Zealand. Simulation techniques involve the building of models which represent reality. Both engineers and economists have developed mathematical models simulating aspects of interest. The technique of storage-behaviour analysis, widely used as the standard approach to this problem is essentially a simulation technique. Only recently, with the development of high-speed large capacity computers has it been possible to represent satisfactorily the complex and dynamic environment of real life situations. Hydrologists, probably ahead in the simulation field, have developed some hydrological models of catchment behaviour which might be extended to allow evaluation of water-resources behaviour development.

Parametric catchment models involve a computer simulation of the physical characteristics of the catchment in which such parameters as infiltration rates, evapotranspiration losses and soil moisture storage capacities are included, and the catchment is represented essentially as a series of water stores. The most highly developed of these models is the Stanford Watershed Model in its various forms (10, 11). This model aims at reproduction of the land phase of the hydrologic cycle and utilises daily, hourly or smaller time increments of rainfall as input to generate continuous daily or hourly hydrographs. A model of the same general type developed by Boughton (2) is now under further development at Lincoln College. It should be noted that the application of these models is not restricted to assumptions of linearity in the modelled system.

The flexibility of the simulation approach enables the examination of two important aspects of water resources developments.

(i) Operating procedures of established projects,

and

(ii) evaluation of variation in the existing number of water structures e.g. the addition of reservoirs etc,

The first aspect is largely one of finding the most desirable operational pattern; the second suggests the use of simulation in the economic evaluation of additional projects.

Simulation to provide measurements of the economic value of a project involves four steps (19).

(a) formulating the pre-project model - tracing the cause and effect feed-back loops that link the system together,

(b) formulation of a mathematical model and the generation of the model's behaviour,

(c) testing the validity of the model by comparing mathematical results with the actual system, and revision if necessary until an acceptable representation is achieved,

(d) expansion of the model to include the proposed project and generating the behaviour of the new system. Comparison of these results with (b) provides a measure of the effect of the proposed project.

These four steps rely on specification and incorporation of technical data. In fact the model is largely a technical one - the addition of benefit and cost functions to the model provides economic information. The Harvard Water Resources Programme, the first standard reference for simulation for water resources evaluation, introduces an economic "response surface", (22) measuring the present values of net benefits originating from the system.

No optimisation procedures are built into the simulation approach - knowledge is gained by repeated trials until better and more "near optimal" solutions are obtained. Quite sophisticated "sampling" procedures are available (22) to enable a close approach to optimality.

WATER RESOURCE DEVELOPMENT IN NEW ZEALAND

In common with most other countries in the world, the "state of the arts" in water resources development in New Zealand is well below optimum. The lack of skilled technical staff, the slow emergence of the economist in this field, and the public emotion involved has meant that government has been forced to develop water resources by rule of thumb. The result has been a piece-meal approach to water resources planning. It is no longer original, (but still relevant) to point to the dribble of funds allocated to water resources research and to exhort government to embrace modern techniques of river-basin planning.

Let us review briefly the institutional framework within which water policy is determined in New Zealand. An act of Parliament in 1941 established the Soil Conservation & Rivers Control Council, and catchment boards in "problem" districts. There are at present 13 catchment boards, three catchment commissions and the Waikato Valley Authority, covering three quarters of New Zealand.[11] The catchment boards are responsible for most river control, soil conservation and drainage works; some works are the responsibility of drainage boards and government departments.

In its wisdom, government has created a system of subsidies for some of the components of watershed development;

(a) River control - subsidies vary generally from $1 for $1 to $3 for $1, for construction work, with subsidies also available for maintenance.

(b) Drainage - subsidies rarely exceed $1 for $1 for construction work and $1 for $2 for maintenance.

(c) Soil conservation - subsidies vary generally from $1 for $1 to $2 for $1.

(d) Community irrigation schemes - $3 for $1.

That subsidies should be granted is not unusual, or necessarily undesirable; what is disturbing is the apparently illogical and inflexible basis of determining the rate of the subsidy. A subsidy should be justified if, and only if, there is a divergence between the social worth (the value to the nation) and the private worth (the value to the individual) of a project, and the extent of the subsidy should directly reflect the size of this divergence. This means that any project, e.g. an irrigation scheme, should be evaluated from both the viewpoint of the nation, and that of the individual. The individual should contribute to the project what the water is worth to him, and the subsidy level should be varied to cover the divergence between this amount and the social benefit. If these criteria do not apply, transfer payments are made from public funds to the individual if the subsidy is too large, and vice versa if too small.

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[11] See New Zealand Yearbook, 1966, p.279.

To the economist the statement that the level of subsidy for river control work varies "depending on the capacity of the property owners to meet their share of the cost" [11] is strange logic, since the property owner's share of the cost should be the (net) value of the water to him, and if fairly assessed he can meet this cost.

The catchment boards are obliged to operate within a similar restricted institutional framework. Projects are put forward for subsidy to the Soil Conservation and Rivers Control Council with each board feeling obliged to request as high a subsidy as possible for any project. Projects have seldom been evaluated professionally from the national viewpoint. [12] After a wave of the official wand the subsidy level for each project is struck by the Council. The remaining cost of a project is allocated among the farmers in the proportion in which benefits accrue. The amount allocated to catchment boards as subsidies is fixed annually. Rationalisation of the subsidy system could well increase the number of projects catchment boards could undertake, but this would necessitate the systematic and uniform presentation of economic reports on all proposed projects.

Hayward has compiled the only reasonably comprehensive report of a river catchment in New Zealand (20). This excellent book provides physical and technical data, land use and productivity information. One conclusion reached is that land in capability classes VII and VIII should be destocked, and that run-holders should be compensated according to the capitalised productive value of the land. Unfortunately the report goes on to say (p.175) that "compensation should not be an unconditional handout", and recommends, that the "compensation be conditional upon its reinvestment in the property". Unless unstated non-economic grounds exist for this recommendation, some economic justification is necessary before compensation for lost income is made conditionally.

I shall comment only briefly on the use of water for electricity, mainly because, to my knowledge, literally no substantial economic appraisal of electricity generation in New Zealand has been published. It may be that they have been completed and not published, or it may be that no appraisal has been done. It is easy for the amateur in this field to talk glibly about what the government should and should not do, and how water resources should or should not be used for power generation. In fact it is probably a privileged few with access to the appropriate information in Wellington who could supply the information needed for an economist to make meaningful statements. Certainly, huge amounts of investment have been poured into hydro-electric stations in New Zealand with no criteria for public judgment except the finished product, and the fact that we are assured it is a "good thing". Ward (44), has called our attention to the fact that electricity supply development is the biggest claimant on capital funds - of the order of 30 per cent of government capital formation in 1966. By plea is not for fewer

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[11] See New Zealand Yearbook, 1966, p.279.

[12] e.g. drainage schemes - See Johnson's bibliography (25). The example set by the North Canterbury Catchment Board could well be emulated by other boards.

hydro-electric stations and more nuclear stations so much, but for the politician to insist on economic evaluation by established techniques, and the application of reasonable criteria before committing huge sums of public money to large construction projects.

One report I have sighted (23) attempts to compare the economics of using a cusec of water in hydro-electric power, stock water and irrigation in the Mackenzie Basin. Unfortunately the valuation of the water is based on gross value of possible output, all of which is imputed to water. The allocation of water among competing uses should be based on estimates of MVP in each use (34).

The institutional framework within which water resources are administered in New Zealand is under revision. New legislation provides for a National Water & Soil Conservation Authority, Regional Water Boards, a modified Soil Conservation & Rivers Control Council, a Pollution Advisory Council and a Water Allocation Council. These bodies will have to make important decisions on licencing, water allocation, subsidies and so on. This occasion of a long over-due administrative re-organisation should be the opportunity for re-examination of the framework within which decisions have been made in the past. Little benefit can result from the creation of additional administrative groups unless there emerges a clear and rational water policy for New Zealand; unless these groups contain at least some professionally trained experts; unless sectional interests and pressure groups are kept in perspective; and unless sufficient economic information is available [13] on proposals to allow economic justification for decisions reached.

Finally, I would enter a plea for the publication of economic reports prepared by government advisers on hydro-electricity projects and other projects related to the use of water resources. If no publishable reports have been prepared, government must have found considerable difficulty in assessing the desirability and priority of projects. A greater public awareness of water resources problems is essential; publication of economic reports is necessary for informed public discussion.

CONCLUSION

I have outlined the theoretical basis for resource allocation and how it is probably impossible to ensure that real situations conform even approximately to this optimum. The techniques accepted as useful in the economic evaluation of water resources development have been discussed. Some institutional factors in New Zealand which may distort the desirable allocation of public money have been mentioned. The various professions concerned in water resources development have come of age and should be given the opportunity of devoting some of their energies to a modern approach to this vital question.

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[13] Officers of the Department of Agriculture have capably evaluated many proposed irrigation projects using discounting techniques in recent years; See Johnson's bibliography (25).

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LEGISLATION FOR WATER RESOURCES DEVELOPMENT

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Last year the New Zealand Parliament passed the very important Water and Soil Conservation Act which comes into operation on the 1 April 1968 and which will have a very profound effect on the development of water resources in this country.

Before examining this Act and the results we hope to achieve it is desirable to refer to the existing law relating to water and to the factors which led to the enactment of this legislation.

The existing law as to water is to be found in the Common Law of this country as derived from the Common Law of England and in many different Acts of Parliament administered by some ten Government Departments. With a few exceptions, the common law right of a riparian owner to abstract water from a river flowing past his land, without the consent of any responsible body, is not abrogated by the Acts now in operation and there is no central authority responsible for planning the water resources of the country.

The right of a riparian owner to abstract water for certain purposes is the most important common law doctrine relating to water. This doctrine was enunciated by Lord MacNaghten in 1904 in the following terms:

"There are, as it seems to me, three ways in which a person whose lands are intersected or bounded by a running stream may use the water to which the situation of his property gives him access. He may use it for ordinary or primary purposes, for domestic purposes, and the wants of his cattle. He may use it also for some other purposes - sometimes called extraordinary or secondary purposes provided those purposes are connected with or incident to his land, and provided that certain conditions are complied with. Then he may possibly take advantage of his position to use the water for purposes foreign to or unconnected with his riparian tenement. His rights in the first two cases are not quite the same. In the third case he has no right at all ....In the exercise of his ordinary rights he may exhaust the water altogether. But no lower proprietor can complain of that. In the exercise of rights extraordinary but permissible, the limit of which has never been accurately defined and probably is incapable of accurate definition, a riparian owner is under considerable restrictions. The use must be reasonable. The purpose for which the water is taken must be connected with his tenement, and he is bound to restore the water which he takes and uses for those purposes substantially undiminished in volume and unaltered in character."

Lord MacNaghten's statement of the law has been confirmed as recently as 1966 in an English case in which it was held that spray irrigation was an extraordinary use of water and that a riparian owner had no right to take water for this purpose as only a very small quantity of water taken from a river would return to it.

As can be seen from Lord MacNaghten's statement the extent to which water may be taken from a river for extraordinary purposes is far from clear and the need to obtain a permit from some central authority to take water other than for domestic purposes would clearly establish a person's right to water so as to justify the expenditure by him on irrigation works or spray and other equipment.

As previously mentioned there are numerous statutes in force in New Zealand dealing with different aspects of water. The dividing line between the functions of some of the bodies set up by these Acts is difficult to define and different laws apply in different regions. There is no overall body to ensure that the best use is made of water, that it is not wasted or that usage is allocated on a fair basis.

The principal general acts dealing with water are:-

1. Land Drainage Act 1908
2. Rivers Boards Act 1908
3. Swamp Drainage Act 1915
4. Coal Mines Act 1925
5. Mining Act 1926
6. Public Works Act 1928
7. Soil Conservation and Rivers Control Act 1941
8. Land Act 1948
9. Harbours Act 1950
10. Geothermal Energy Act 1953
11. Underground Water Act 1953
12. Waters Pollution Act 1953
13. Municipal Corporations Act 1954
14. Counties Act 1956
15. Health Act 1956

Of these, the Act which has the widest effect in respect of water and which is most closely tied in with the Water and Soil Conservation Act is the Soil Conservation and Rivers Control Act 1941 which constitutes the Soil Conservation and Rivers Control Council.

The functions of this Council are to assess the nature and extent of soil erosion and flooding in New Zealand, to investigate and develop measures to ameliorate the effects of these things and to promote flood and erosion control and land drainage by means of advice, direction and financial assistance. The Council receives about $5.5 million per annum from Government, the greater part of which is distributed amongst catchment authorities to supplement funds raised locally to meet the cost of works. This Act provides for the creation of Catchment Boards as local Government authorities to administer catchment districts which are made up of one or more whole river catchments. These Boards become Regional Water Boards under the Water and Soil Conservation Act and will be responsible for issuing permits to take and use water. Under the Soil Conservation and Rivers Control Act Catchment Boards have power to levy rates to cover cost of administration and works and to investigate, design and carry out and maintain works for flood and erosion control, soil conservation and land drainage. The majority of members of such Boards are elected by the territorial local authorities within the district, the minority being appointed from officers of Government Departments.

The other Act which is of particular importance in relation to the Water and Soil Conservation Act is the Waters Pollution Act 1953 which constitutes the Pollution Advisory Council whose function it is to promote the prevention or reduction of pollution of water by research, education, the formulation of codes and model by-laws about the treatment of trade wastes, and by determination of standards of quality for the water in any stream. The Council has eleven members who include representatives of local and central government and industry.

Now to turn to the practical side of water resources and to the physical factors which led to the new Act. I have no doubt other speakers will have emphasised our complete social and economic dependence on water and the ever increasing demands being made on the sources of supply in New Zealand, and in most other countries throughout the world, by a rapidly growing population and greatly increased agricultural and industrial production. This increasing demand for water has led many overseas countries to enact legislation controlling the use of water and providing for the comprehensive planning of available water resources. As was said by Sir William Goode at the International Conference on Water for Peace held in Washington last year "The proper management of a country's water resources has two basic requirements. First, it is essential to ensure that the immediate situation is safeguarded.....The second requirement is to plan the development of water resources to meet future needs over a much larger area and a larger period than in the past, and thereby to ensure that resources are used to the best advantage of the whole country."

Although New Zealand is blessed with an adequate fairly evenly distributed rainfall there are areas where rainfall is slight and shortage of water is serious at times; and there are other areas, particularly urban areas, where the demand for increased quantities of water results in competition between water users. These days the use of irrigation for agricultural purpose is assuming greater importance, more use is being made of spray irrigation with its high evaporative factor, large, comparatively new industries such as pulp and paper mills, oil refineries and steel mills require huge amounts of water while the generation of electricity makes it necessary to prevent any diversion of water in some cases while in other cases the diversion of rivers and lake waters are an integral part of the hydroelectric scheme.

All these factors, legal, physical and economic - have made it essential to assume greater control of water in this country by vesting in the Crown the sole right to use natural water and by setting up a National Water Authority to plan and co-ordinate the water resources of New Zealand.

Provision to this effect is contained in the Water and Soil Conservation Act 1967 which comes into force on 1 April 1968.

The Act recites that its purpose is to promote a national policy in respect of natural water, and to make better provision for the conservation, allocation, use and quality of natural water and for promoting soil conservation and preventing damage by flood and erosion, and for promoting and controlling multiple uses of natural water and the drainage of land, and for ensuring that adequate account is taken of the needs of primary and secondary industry, water supplies of local authorities, fisheries, wildlife habitats, and all recreational uses of natural water. You will appreciate from this the many facets of water the Act embraces.

The Act generally applies only to "natural" water which is defined as meaning all forms of water but does not include water while it is in any reservoir used for the water supply purposes of any local authority or while it is in any pipe, tank or cistern.

The Act provides for the constitution of the National Water Authority with a membership of seven, the Chairman being the Minister of Works, and directs that a specified wide class of bodies dealing with water including the Soil Conservation and Rivers Control Council, Catchment Boards, the Pollution Advisory Council, River Boards, Drainage Boards, Water Boards, Borough Councils and County Councils shall give effect to the policy and directions of the National Authority.

The functions of the Authority are very extensive. They are set out in Section 14 of the Act. The Authority has all the functions rights powers and duties conferred on the Soil Conservation and Rivers Control Council and the Pollution Advisory Council. More particularly it has the functions and powers set out in subsections (3) and (4) of Section 14 as detailed in the Schedule to this paper.

The Act sets up a new Council called the Water Allocation Council whose main functions will be to organise the establishment of records of availability and the volume and location of resources of natural water and to supervise and guide, as it seems best in the public interest, the settlement of competing demands in respect of natural water.

The National Water Authority, the Soil Conservation and Rivers Control Council, the Pollution Advisory Council and the Water Allocation Council are grouped together under the Act to form the National Water Organization and the Authority is empowered, subject to its continued overriding responsibility, to apportion between itself and the three Councils all its functions but so that normally:

(a) Matters of water and soil conservation and river control are delegated to the Soil Conservation and Rivers Control Council;

(b) Matters of pollution and quality of natural water and other water are delegated to the Pollution Advisory Council;

(c) Matters of allocation of natural water and matters of co-operation with and between local authorities and suppliers of natural water in solving problems of distribution and economy of use of natural water and other water are delegated to the Water Allocation Council;

(d) Matters of national policy, general supervision of the administration of natural water and the giving of advice to any Minister of the Crown are retained by the Authority.

The Act constitutes as Regional Water Boards, Catchment Authorities (at present 16) constituted under the Soil Conservation and Rivers Control Act and the Waikato Valley Authority. Provision is made for a total number of 25 water regions and Regional Water Boards for the North and South Islands of New Zealand. Regional Water Boards for districts which have not an existing Catchment Authority will be constituted by Order in Council on the Recommendation of the Local Government Commission. Regional Water Boards will be the regional agent for the Authority and the three Councils.

A most important function of these Boards is the granting of permits to take and use natural water. Section 21 of the Act provides that except as expressly authorized by or under the Act or any other Act the sole right to dam any river or stream or to divert, take, use or discharge water from or into any natural water is vested in the Crown but it is lawful for any person to take or use natural water that is reasonably required for domestic needs, the needs of animals and fire fighting.

The common law rights of a riparian owner are accordingly considerably abrogated by this Act although the main right, namely, the right to take water for domestic purposes, may still be exercised without the need to obtain a permit.

A right of appeal against the refusal of the Regional Water Board to grant a permit or against conditions attached to such permit is allowed by the Act to the Town and Country Planning Appeal Board.

Reasons which lead to the decision to convert the existing catchment boards into the regional water boards were that catchment boards have functioned very satisfactorily for some twenty years in the important fields of flood prevention and soil conservation and that the boundaries of catchment districts, following the watershed separating one catchment from the next, would enable the administration of all the water resources in each catchment or group of catchments or river basins, to be vested in one authority. There are very great advantages in the Regional Water Board being given full control over all aspects of natural water in its district from the time it falls to the ground until it reaches the sea whether by way of above or under ground flows: only in this way can it fully accept its responsibility of determining conflicting interests and of providing comprehensive management of the water resources of the region.

CONCLUSION

A very progressive and vital step has been taken in vesting in the Crown the sole right to take and use water but the Water and Soil Conservation Act represents only the first step in a new programme for promoting a national water policy. Further consolidating supplementing and amending legislation will obviously be required in the implementation of this policy and one of the most important matters requiring consideration by the Authority at an early date will be the extent to which existing legislation relating to water should be consolidated and placed under the control of fewer Ministers and Departments.

The successful implementation of the Water and Soil Conservation Act will, to a great extent, depend on the calibre of the men appointed to the National Water Authority and on the effectiveness of their guidance and planning of our resources of soil and water in the national interest. The policies adopted by this Authority will be wide felt and may even imtrude into the field of town and country planning to assist in halting urban sprawl in the interests of soil conservation. The Authority is fortunate in having as its chairman the Minister of Works (the Hon. P.B. Allen) who as Minister charged with the administration of the Soil Conservation and Rivers Control Act, the Underground Water Act, the Town and Country Planning Act and the Public Works Act has had very wide experience in matters pertinent to those embraced by the Water and Soil Conservation Act.

Under the Act technical and administrative services to the National Water Authority and the Water Allocation Council are to be provided by officers of the Ministry of Works and to this end there has been set up within the Ministry a separate Water and Soil Division staffed with men highly qualified and experienced in engineering, hydrology, and soil conservation.

SCHEDULE

FUNCTIONS AND POWERS OF NATIONAL AUTHORITY

Section 14

(1) ....

(2) ....

(3) Without restricting the foregoing provisions of this section, the Authority shall also have the following functions and powers:

(a) To examine problems concerning, and make plans in respect of, -

(i) The allocation and quality of natural water;

(ii) The control of erosion on the banks of rivers, the shores of lakes, and the seashore; and the control of flow and flooding in and from rivers and lakes;

(iii) Conservation of natural water;

(iv) All enactments and rules of law relating to natural water;

(v) The needs of fisheries and wildlife and all other recreational uses of natural water.

(b) To advise the Minister from time to time as to what enactments are desirable to ensure the most efficient administration of natural water and the conservation of soil and natural water in the national interest:

(c) To keep under review and make recommendations concerning the constitutions, functions, and performances of the Councils, Regional Water Boards, and other bodies concerned with the administration of natural water and soil under this Act:

(d) To coordinate all matters relating to natural water so as to ensure that this national asset is available to meet as many demands as possible and is used to the best advantage of both the country and the region in which it exists in the course of nature:

(e) To exercise, in relation to erosion, accretion, and pollution in estuaries and on the sea front and in all other places within the outer limits of the territorial sea of New Zealand, all of the functions and powers conferred on the Soil Conservation and Rivers Control Council by or under the Soil Conservation and Rivers Control Act 1941, and on the Pollution Advisory Council by or under the Waters Pollution Act 1953, as if the functions and powers of those Councils under those Acts extended to the said estuaries, sea front, and places:

(f) To exercise all the functions and powers conferred on any public authority or officer thereof in respect of natural water by or under the Mining Act 1926 and the Public Works Act 1928; and to advise the Minister of Works and the Minister of Mines as to the exercise of their functions and powers, and of the functions and powers of the Governor-General, under those Acts and under section 33 of the Finance Act 1938 and section 39 of the Finance Act (No.2) 1939:

Provided that nothing in this paragraph shall prevent the exercise by any public authority or officer of any such function or power:

(g) To control the damming, diversion, taking, and use of natural water, and the discharge of anything into any natural water, so far as any such acts may affect the quality and availability of natural water for other purposes:

(h) To advise the Minister as to the need for the appropriation of money by Parliament for the purposes of this Act and as to the administration of money so appropriated:

(i) To organise, where it considers necessary or where any enactment so requires, the registration of and the recording of information concerning rights and duties relating to the damming, diversion, taking, use and pollution of natural water:

(j) To guide national and local administration of natural water and of soil conservation in the best public interests:

(k) To guide and encourage research in matters relating to natural water and soil conservation and the application of knowledge thereby acquired:

(l) To demonstrate and encourage the development and use of efficient methods of conservation of soil and natural water and other water:

(m) To promote the best uses of natural water, including multiple uses, and to allocate natural water between competing demands:

(n) To negotiate the acceptance by appropriate authorities of added responsibilities in respect of natural water and of soil conservation:

(o) To fix, after consultation with representatives of all interested bodies and persons known to the Authority, maximum and minimum levels, and minimum standards of quality to be sought or permitted for the natural water in lakes, both natural and artificial, and the minimum acceptable flow and minimum standard of quality of the natural water of any river or streamm and, where desirable, to fix the maximum range of flow and arrange for the retention or disposal of surplus natural water:

(p) To promote the training and education of persons engaged in the administration of natural water and other water and in soil conservation, and the dissemination of information to the public.

(4) Without restricting the foregoing provisions of this section, the Authority shall also have the following functions and powers:

(a) To organise the establishment of records of availability, volume, and location of resources of natural water, of existing rights to natural water and other water, and future requirements in respect of natural water, and of such matters as may seem useful as a basis for allocation of natural water between competing demands, and to ensure that the information is made available to interested local authorities:

(b) To supervise and guide, as to it seems best in the public interest, the settlement of competing demands in respect of natural water:

(c) To promote the adequacy of natural water at all times:

(d) To promote knowledge of and efficiency in public use of natural water, including irrigation, water for animals, fire fighting, and rural supplies of natural water:

(e) To make such investigations in respect of the water-supply industry or any part or aspect thereof as may from time to time appear to it to be necessary or desirable or be requested by any local authority engaged in the industry; and to make consequential recommendations to the Minister and local authorities:

(f) To advise local authorities and others on the efficient transfer and use of natural water and other water:

(g) To foster the proper training of waterworks personnel, including the direction of any such training schemes that are supported by grants out of money appropriated by Parliament:

(h) To examine, in relation to particular processes, the qualities of natural water required for different industrial purposes, and the possibilities of economic use of natural waters of different qualities for complementary purposes:

(i) To investigate and disseminate information to the public regarding the most economical means of reducing peak demands on water-supply systems:

(j) To make and encourage investigations of the requirements of industry in respect of natural water:

(k) To carry out hydrological research, and to promote research in matters where, because New Zealand conditions may differ from those upon which work has been done overseas, there is a lack of research data which would enable the applicability of overseas work to New Zealand conditions to be assessed:

(l) To take into account the present and future needs of primary and secondary industry, water supplies of local authorities, and all forms of recreation, and to have due regard to scenic and natural features and to fisheries and wildlife habitats when planning and advising on the allocation of natural water.

EDUCATION FOR WATER RESOURCES DEVELOPMENT IN AUSTRALIA AND NEW ZEALAND

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1. INTRODUCTION

Australia and New Zealand, two neighbouring and closely related nations, occupy the south-western corner of the Pacific region. Settled as English colonies a century and a half ago, and now independent members of the British Commonwealth, each has developed a European, English-speaking population of predominately British origin and outlook. Although traditionally looked upon as agricultural countries, and still depending for the major part of their export income on agricultural and pastoral products, Australia and New Zealand are highly industrialised and the most technologically advanced nations in South East Asia or Oceania. Essentially similar in political outlook and social and governmental structure, and having always been closely associated in a military sense, the two nations face unique political problems as a result of their small populations, their geographical isolation and their traditional orientation towards Britain and the U.S.A. rather than their Asian neighbours.

Whilst both countries are rapidly developing manufacturing industries and Australia, in particular, is emerging as an exporter of manufactured goods to South-east Asia, both countries depend for a very high proportion of their export income on the sale of wool, meat, wheat and dairy products to Europe and, in particular, to Great Britain. This situation introduces major economic problems, partly because the financial structure of both countries is considerably affected both by fluctuations in the world prices of wool, wheat and dairy products and the effects of seasonal conditions on export production levels and partly because of the likely entry of Great Britain into the European Economic Community.

In countries so dependent upon pastoral and agricultural production it is inevitable that the national economy be closely connected with water resources development. The climatic and topographic factors which determine the types and distribution of agricultural production determine also the distribution of water resources; whilst much of the development of these resources must be undertaken in the light of agricultural and pastoral needs and problems. This is particularly so in Australia, where rainfall is low, erratic in occurrence and unevenly distributed and severe droughts may produce major fluctuations in stock numbers and production levels. It is also so, but for somewhat different reasons, in New Zealand, where the predominant feature is one of rainfall excess and problems of flooding, drainage and erosion are paramount.

2. WATER RESOURCES DEVELOPMENT IN AUSTRALIA & NEW ZEALAND

Although Australia and New Zealand have a very great deal in common, there are marked differences in the nature of their water resources and the problems associated with the development of these resources.

Australia is large, compact land mass having an area of about 3 million square miles, or almost the same area as the continental U.S.A. Geologically it is very old, and except for a chain of relatively low mountains running the length of its eastern seaboard it approximates to an extensive, low and featureless plateau. Whilst the extreme north of the continent comes under monsoonal influences and receives a comparatively high summer rainfall, and the far south receives a regular winter rainfall, the greater part of the country lies athwart the Horse Latitudes and receives low and erratic rainfall, with frequent droughts of considerable severity. The average rainfall for the whole of the country is just over 16 inches per annum; only 11 percent of the total area receives more than 40 inches and two-thirds receives less than 20 inches, making Australia the driest of all the continents. (1)

A similar pattern is reflected in the availability of surface water. The average annual discharge of all the Australian rivers totals just over 200 million acre feet, representing an average depth of runoff of only 1½ inches and equalling only half the annual discharge of the Mississippi River. The drainage pattern is poorly distributed and about one third of Australia has no rivers at all, the bulk of the surface water resources being concentrated in coastal rivers and the comparatively well-watered eastern states. (2)

Whilst average rainfall is low, it is poorly distributed both in space and in time. Recorded average annual rainfalls vary from less than 5 inches to more than 200 inches, but there are many districts where no rain may fall for periods of several years. This difficulty is aggravated by high rates of evaporation, and over more than 90% of the country the annual rainfall is less than the potential annual evapotranspiration loss. On the other hand, when rain does fall it may do so with high intensity and flooding is common, particularly on the short, steep rivers of the eastern coast where serious flood damage may result from intense, long-duration rainstorms produced by tropical cyclone influences.

Australia's major water resource problems revolve around water conservation and involve firstly long-term storage of water to overcome temporal variations in rainfall and runoff, and secondly, transport of water to overcome spatial maldistribution. Large conservation reservoirs having design storage periods of three years and more are necessary; Sydney, for example, has a greater per capita capacity of storage for water supply than any other city of comparable size in the world, and yet water rationing is a common experience for Sydney householders. (3) Water must sometimes be transported great distances to overcome poor areal distribution; there are several town water supply pipelines 200 miles and more in length and irrigation water is diverted from the eastern watershed to drier areas hundreds of miles to the west.

A related problem of major importance is that of inefficient utilisation of a scarce resource. For example in the city of Adelaide, which is located in an arid state with virtually no surface water sources at all, 48 percent of all the water consumed is used on household gardens. Evaporation losses may account for as much as 80% of the water stored in reservoirs and it is no accident that major developments in evaporation suppression have come from Australia.

The Stanford Research Institute, in a report on the Development of Australia completed in 1963 (4), concluded that "water is Australia's biggest problem". The further development of Australia must depend upon the wise and efficient development of water resources, power and transport and the education and training of engineers, scientists, economists and administrators for this purpose is clearly a vital factor in determining Australia's future.

By contrast with Australia, New Zealand is a well-watered land where water excess is more a problem than water deficiency. New Zealand comprises two large islands and a number of smaller islands located some 1200 miles to the south-east of Australia. Geologically it is very young and, unlike Australia, is characterised by high mountain ranges, lying athwart a maritime airstream and associated with high annual rainfalls, permanent river systems and large areas of snowpack, lake and glacier storage.

The average rainfall for New Zealand is high but for the greater part annual rainfall ranges between 25 and 60 inches. The only areas having rainfalls of less than 25 inches are found on parts of the east coast of the South Island; on the west coast of the same island annual totals reach as high as 300 inches. (5)

Over the greater part of the country rainfall is spread evenly throughout the year and soil moisture and temperature conditions are particularly favourable for the growth of the lush pastures for which New Zealand is famous. Summer droughts of limited intensity do however occur and on the east coast farm production can be considerably increased by irrigation.

Unlike Australia, New Zealand is endowed with many large, snow-fed rivers which flow throughout the year and provide outstanding potential for hydro-electric development;. 80 percent of the country's total installed generating capacity is in hydro-electric stations. The largest river, the Clutha, although only 200 miles in length, yields approximately the same annual discharge as the Murray-Darling, Australia's largest river system, which drains a catchment 50 times as large (5).

The combination of high and intense rainfall with young, steep mountains, highly fractured rock and highly erosive soils, and a history of unwise land use, has created in New Zealand major problems of soil erosion, sedimentation and flooding. New Zealand presents some of the most spectacular erosion in the world (6) and major efforts in soil conservation and catchment control, as well as extensive river control works, have become necessary. In the wet North Island the drainage of agricultural soils is a major factor in pastoral production. Serious problems of water conservation have not yet arisen and the major dams constructed in New Zealand have all been built for hydro-electric power development. New Zealand's water resource problems, therefore, revolve principally around water excess rather than water deficiency. There is growing evidence, however, that stock water conservation is essential to the meat and wool industry and that irrigation can lead to substantial increases in agricultural production, particularly in the drier areas of the South Island. There is also a growing awareness of the need for multi-purpose development of water resources, whilst the increasing incidence of water pollution is focussing more critical attention upon water resources problems.

Although perhaps not so dramatically evident as in Australia, water is equally one of New Zealand's biggest problems and the need for education and training of water resources personnel to handle the many facets of this problem is becoming a matter of vital importance. This need is about to become greatly accentuated, following the passing in 1967 of a comprehensive Water and Soil Act (7) requiring a new approach to water control and water resources development.

3. WATER RESOURCES PERSONNEL IN AUSTRALIA AND NEW ZEALAND

In Australia, water resources development has traditionally been the province of the civil engineer, who has been responsible for the planning as well as the execution of works for water conservation and control. The average Australian is intensely conscious of drought and flood and accepts the building of storage dams and the development of irrigation projects as work of national importance which can be undertaken with little regard for economic justification. Australian engineers have developed a considerable skill in the design and construction of hydraulic structures and made many notable achievements in this field, of which the Snowy Mountains Scheme is perhaps the best-known example. It might be supposed that the Australian engineering schools have developed a parallel facility in teaching and research in the water field, but this is by no means the case; of eleven University civil engineering departments only one has developed a substantial degree of specialisation in water engineering. The majority of Australian graduates in Civil Engineering, although well-trained in fluid mechanics, receive little or no education in hydrology or economics and have little understanding of the many socio-political factors vital to water resources development.

This situation might be acceptable if personnel trained in other disciplines took an active part in water resources development. Because, however, of the common Australian acceptance of the principle that water development projects must automatically be a good thing, either for today or for the future, little attention is paid to the economic evaluation of water projects and Government relies for overall water planning on the recommendations of its engineering administrators. No Australian university provides any significant training in aspects of water resources development for students outside the engineering schools, and university economists and others who have questioned the wisdom of new water development projects have received scant notice.

There is little evidence in the Australian engineering literature that serious attention is given to the economic justification of public water projects or to the more general questions of the best alternative uses of water or capital. Of the 200 papers published by the Institution of Engineers, Australia between 1929 and 1964 describing the design and construction of major water development projects, only one includes any consideration of benefit-cost analysis, whilst only four include even a discussion of the hydrologic basis upon which the size of the project was determined (8).

In New Zealand problems of water resources development and control have been divided amongst several groups of technologist. As in Australia, both the planning and construction of major works for flood control or hydro-electric and water supply development has been the province of the engineer. Almost invariably this development has been undertaken on a single-purpose basis and, because of a lack of hydrologic data and a general acceptance that river control works and hydropower projects are automatically a good thing, with little consideration of hydrologic or economic alternatives. Prior to 1966 the two engineering schools in New Zealand provided only a token training in hydrology and no training whatever in engineering economics. Whilst a tribute must be paid to the skill of New Zealand engineers in the design and construction of major hydraulic structures, more often than not under extremely difficult foundation conditions and in the face of considerable uncertainty about flood flows, doubts can be raised in retrospect about the wisdom of their overall water development policies. These policies are largely determined within one Government department which is responsible for all major civil construction activities.

Soil conservation and watershed management in New Zealand has been almost entirely the province of a different group, the soil conservators. The majority of these men have received some basic training in agriculture, with emphasis on agronomy, soil science and farm management; they have little or no training in hydrology or fluid mechanics, although they are largely concerned with water control practices. Whilst the two agriculture schools in New Zealand provide some formal training for soil conservators, only one or these offers any specialisation in hydrology and this has only been available since 1965. Whilst again a tribute must be paid to the work these men have accomplished in the face of a limited hydrologic background and an almost total absence of hydrologic data, many of their development programmes can be criticised in retrospect from hydrologic and economic viewpoints.

Water resources research and investigation, including the collection of basic hydrologic data, is undertaken in New Zealand by a variety of personnel from many disciplines. Science graduates, particularly geologists, geographers and agriculturalists, are far more numerous than engineering graduates in research and investigation activities. This is in direct contrast to the Australian scene, where hydrologic research and investigation is very largely a civil engineering function. In New Zealand this results in an inter-disciplinary approach to many research problems and may eventually lead to a similar approach in overall water planning. It has the serious disadvantage, however, that a majority of the personnel engaged in hydrologic research and investigation have had little or no education in basic hydrology, which has until very recently been taught only in the engineering schools.

Australia and New Zealand have developed basically similar attitudes to water resources development, but for rather different reasons. In Australia, on the one hand, the importance of water conservation is so widely accepted that politicians and the general public are content to leave water planning to Government engineers and accept their recommendations without serious question. In New Zealand, on the other hand, it is widely assumed that there is water in abundance and again the recommendations of Government engineers are accepted unquestioned. In both countries the personnel responsible for water development have not been trained in the basics of hydrology or the techniques of resource allocation and project evaluation. In neither country is the need for an inter-disciplinary approach to water resources problems fully appreciated, nor is the importance of overall planning for the integrated, multi-purpose development of water resources on a regional or national basis properly recognised. It is clearly essential to provide educational programmes in all aspects of water resources development for those engineers and other specialists to whom water development is entrusted before this situation can be rectified.

Any criticism of personnel engaged in water resources development must be tempered by a consideration of their working objectives, as specified by Government. Many Australian water projects which have come under scrutiny in recent years because of an apparent lack of economic justification have been constructed largely for political objectives. It is perhaps unfair to censure an engineering organisation for failing to make a full economic appraisal of a new project, when it has not been required to do so by the Government concerned with finding the funds to construct the project. Whilst this paper is concerned with university education for professional personnel engaged in water resources development, the need to educate both the legislators, and the voters who support them, in the basic principles of water resources development cannot be over-emphasised.

4. EDUCATION FOR WATER RESOURCES DEVELOPMENT

Professional specialisation for personnel entering the water resources development field is best introduced at the post-graduate level. Water resources personnel may be drawn from several disciplines and a sound undergraduate training is an essential first requirement. To provide a basis for further education at post-graduate level some limited undergraduate specialisation is however necessary; thus civil engineers should have a sound background in fluid mechanics and a basic grounding in principles of engineering hydrology and engineering economics. In any case, present conditions in Australia and New Zealand are such that many of the personnel recruited for water resources development activities will be unable, for one reason or another, to take specialist courses at post-graduate level. It is therefore important to ensure that first-degree graduates likely to be recruited by water resources agencies have at least some basic understanding of hydrologic science, whether their field be engineering, agriculture, the earth sciences or economics.

At the post-graduate level two categories of education seem to be required. The most urgent need is for formal courses in hydrology, hydro-economics and water resources technology to provide the scope and depth of knowledge not available or desirable in undergraduate courses. A second need is for an opportunity to undertake research in the water resources field, as training for future investigation, research and teaching activities. Where possible the two programmes should be combined, so that all graduate students take formal course-work and those who so elect can continue with research programmes.

The requirements of a post-graduate course in water resources development appear to be quite specific, at least for Australian and New Zealand conditions. In the first place it is essential for all students, regardless of their undergraduate discipline, to take a basic course in hydrologic science. It is also desirable that all students receive a general introduction to the broad aspects of water resources development, with attention to such topics as the hydro-economic principles of resource allocation and project evaluation, water law, developments in water resources technology and the aspects of socio-economic-political activity which relate to water resources development.

In the second place, a range of specialist courses in different aspects of water resources technology should be available on an optional basis to meet the needs of individual students. Such subjects as groundwater hydrology, open-channel hydraulics, sediment transport, watershed management, irrigation and drainage or the design of water resources systems might be included, together with courses in systems analysis, micro-economics and operations research.

In the third place, these courses should be so devised that they can be taken by graduates from a variety of disciplines, particularly engineering, the earth sciences and economics. For this approach to be effective some preparation must be incorporated into undergraduate courses, so that students can enter the water resources programme with a common grounding in the topics they propose to study at the post-graduate level. This multi-discipline approach is important in Australia and New Zealand for two reasons. Firstly, the numbers of students likely to be forthcoming and the number of teaching staff likely to be available will not justify the establishment of more than one or two water resources schools, which must therefore accept students from a range of disciplines. Secondly, and more importantly, many of the problems of water resources development are in any case inter-disciplinary problems which are best tackled by teams rather than by individuals; it is therefore important to engender a spirit of co-operation and understanding at the graduate school level if the establishment and operation of such teams is to be successful.

In the fourth place, as many students as possible should undertake a research project in association with their training programme. This is important because the techniques of water resources development have yet to be fully worked out; at the present time practical development problems become in essence applied research projects wherein it is necessary to make major decisions in the face of uncertainty and in the light of very limited physical and economic data. The water resources specialist should therefore gain experience in the tackling of such projects under the guidance of the water resources school. For preference, such research should be undertaken on a team basis, to strengthen the spirit of inter-disciplinary co-operation and give the student an opportunity to learn the difficult business of solving problems in association with other people.

Two rather different types of graduate programme, which attempt to meet these objectives, have been developed in recent years, one in Australia and the other in New Zealand. The writer was closely associated with both these programmes in their development phases and has gained sufficient experience with them to suggest modification and improvement for future needs.

In Australia the only post-graduate programme which provides any substantial preparation for the water resources development field is offered by the Water Engineering Department of the University of New South Wales in Sydney (8). This is a formal post-graduate course which may be taken in one year on a full-time basis or two years on a part-time basis. It is designed primarily for graduates in Civil Engineering and leads to the degree Master of Engineering Science. The course was developed to its present form in 1963 and is now firmly established.

Students may select four subjects from the following list and one other from any of the Graduate subjects offered by the Engineering faculty. In addition each student must carry out work on a project which may involve a design, an investigation or a piece of research.

The subjects available are as follows -

Hydrology I; Hydrology II; Water Resources Development; Design of Water Resource Systems; Engineering Hydrology; Groundwater Hydrology; Irrigation and Drainage; Hydrodynamics; Hydromechanics; Advanced Hydraulics; Hydraulic Design.

The water resources specialist would normally be expected to take the first three of these subjects, together with two others related to his particular field of interest. On a full-time basis each subject occupies 3 hours per week; a further 6 hours per week is nominally allocated to the project, making a total requirement of 21 hours per week for one academic year.

The subjects Hydrology I and Hydrology II provide a strong background in the field considered basic to all water resources development courses. The topics covered in these subjects include climatology, meteorology and hydro-meteorology, the collection, processing and analysis of hydrologic data, soil physics and the runoff process, flood estimation and flood mitigation, catchment yield and storage design, soil conservation and agricultural hydrology, and an introduction to the planning of water resources development projects.

Perhaps the most interesting subject in the context of this paper is the subject called Water Resources Development, which was developed and first taught by the writer. It provides an integrated study of the hydrologic, technological, economic and socio-political factors which affect the problems of water resources development and includes a consideration of each of the following topics - hydro-economics, including principles of project evaluation and resource allocation, the problems of planning objectives and design criteria; water administration, water law and the public financing of water projects; hydrologic aspects of water development, including assessment of available water resources, water use and demand, and the prediction of future requirements; technological aspects of water development, including techniques for the control, recovery, distribution and utilisation of water resources; and a study of the overall problems of hydro-economic planning, including consideration of irrigation, water supply, power and flood control projects and the problems of multi-purpose and regional development.

The water resources programme at the University of New South Wales was designed primarily for graduates in civil engineering and is well-suited to the requirements of the Australian community. When the writer took up appointment in New Zealand at the beginning of 1965 it soon became apparent that a different approach was needed, due partly to the different nature of the water resources problem and partly to the different nature of the personnel engaged on water resources development activities in that country.

In New Zealand it was not possible to take any specialist courses in the water resources field prior to 1965. Since the early 1950's the two New Zealand engineering schools have taught brief courses in hydrology to civil engineering undergraduates and each has developed a substantial research interest in sediment transport and river control engineering. Agricultural hydrology has been taught at Lincoln College from the early 1960's and special short courses in hydrology have been operated from time to time under the sponsorship of the Ministry of Works. No consideration had however been given to teaching or research in the broader aspects of water resources development prior to 1966.

In New Zealand it has long been accepted that water resources development is the province of the agriculturalist, the forester, the geographer and the geologist, as well as the engineer; the number of scientists working in hydrologic research and investigation is far greater than the number of engineers so employed. It is significant that the first New Zealand graduate programme in water resources was initiated within an agricultural faculty, led to the granting of an honours M.Agr.Sc. degree to an American graduate in watershed management, and was run under the auspices of an agricultural engineering department whose Head is an Australian civil engineer.

At the present time the only formal post-graduate water resources programmes available in New Zealand are offered by the Agricultural Engineering Department at Lincoln College, the agricultural college of the University of Canterbury (10). Two related programmes are available. The first is a formal lecture course of about 9 months duration which leads to the post-graduate Diploma in Agricultural Science. Entry to the course is open to graduates in agriculture, engineering, geology and other disciplines. Four subjects are taken and these are selected from senior undergraduate and masterate courses currently available at the College. For those candidates wishing to enter the water resources field, a basic course in hydrology is mandatory. Other subjects currently available include soil and water engineering, soil conservation, ecology, and production economics.

Additional subjects will be introduced in the future, in conjunction with the masterate programme described below.

The second of these programmes supplements formal course work with a research project and leads to the award of the M.Agr.Sc. degree. Each candidate is required to sit three papers for which he normally prepares himself through a directed reading programme; a formal lecture course in hydrology was first taught in 1967 and other formal lecture courses are being developed for 1968. The course work for the masterate occupies one academic year of about 9 months duration and the full programme can be completed in about 18 months. Admission to the programme is open to graduates in agricultural science, engineering or other disciplines who meet certain pre-requisitie requirements, which include some basic knowledge of hydrology and water engineering. So far as possible the lectures offered for this programme are intended to be interchangeable with those offered for the Diploma in Agricultural Science. Subjects so far taken by masterate students have included hydrology, watershed ecology, and specialised topics in rainfall-runoff relationships and experimental hydrology.

Whilst this programme provides an opportunity for graduates in engineering, science or economics to undertake specialist studies in water resources, it has been found that many such graduates are reluctant to enroll for a course which culminates in the award of a degree in Agricultural Science. From 1968, therefore, a new arrangement will operate for the Master of Engineering within the School of Engineering of the University of Canterbury, so that engineering graduates can take the same type of programme but be awarded an engineering degree (11). It is anticipated that a similar scheme will later be introduced for geologists, and possibly for other scientists, leading to an M.Sc. degree. Graduates in Agricultural Economics are already catered for in the agricultural science programme.

The ultimate objective for these programmes is to provide a common pool of subjects which may be taken by graduates in engineering, agriculture or science and will lead to higher degree awards in each of these fields. All students will attend common lectures and so far as is possible will be encouraged to undertake research activities on a team basis. Every student will be required to take a basic course of lectures in applied hydrology, together with two optional subjects in his own field of interest. The Departments from which graduates are drawn will contribute subjects to the pool, the basic lecture courses in hydrology and water resources development being offered by the Department of Agricultural Engineering, which is best equipped with staff and facilities in this field. A range of subjects likely to be offered in 1970 is as follows -

Applied Hydrology; Water Resources Development; Design of Water Resources Systems; Open Channel Flow; Sediment Transport; Soil Conservation; Irrigation and Drainage; Groundwater Hydrology.

It is proposed that each subject shall occupy about 5 hours per week, making a weekly total of 15 hours formal classroom time.

Parallel developments in undergraduate courses at the University of Canterbury have been planned to provide the pre-requisites needed as a foundation for the graduate programme. A final-year undergraduate Civil Engineering option in hydrology was introduced for the first time in 1966 and a final-year option in agricultural hydrology will be available to Agricultural Science undergraduates from 1968. The most interesting undergraduate development is the introduction of a Bachelor of Engineering programme in Agricultural Engineering, operated for the first time in 1967, which provides for substantial specialisation in hydrology and soil and water engineering to meet the special needs of the New Zealand Catchment Authorities and the Water and Soil Division of the Ministry of Works.

Opportunity is also available for graduates to proceed to a Ph.D. in the water resources field. Such students are required to take some course work in hydrology and water resources development, depending on their previous background and experience.

In 1967 seven students worked towards higher degree awards at Lincoln College as part of the water resources programme; four for the Dip.Agr.Sc., one for the M.Agr.Sc. and two for the Ph.D. Of these seven students two are civil engineers, one holds an agricultural degree, one holds a B.Sc. in geography, one holds a B.Sc. in chemistry, and two hold degrees forestry. The subjects tuaght included hydrology, soil and water engineering, soil conservation, pedology and ecology; research topics ranged from a study of small plot techniques for the measurement of soil erosion to a sophisticated computer model of the runoff process.

It will be apparent that whilst the Australian programme described above is designed primarily for engineering specialists, the New Zealand programme is designed to cater for a variety of disciplines and to engender the spirit of inter-disciplinary co-operation. In doing so it sacrifices something of the depth of specialisation achieved with the Australian programme.

On present indications, however, the flexibility of the New Zealand programme is such that the individual student can work to the limit of his own ability and attain at least the same academic standard as his own ability and attain at least the same academic standard as his Australian counterpart.

The inherent flexibility of this programme, and particularly the future proposal to provide for the award of a higher degree in the student's original discipline, is also a guarantee that the water resources graduate retains his own identity. It is not intended to produce water resources specialists who are all cast in the same mould; it is important to produce men who have the same basic knowledge of the water field, speak a common language and understand each other's point of view, but retain sufficient individual depth of specialisation to play a major individual role in the co-operative activities of a water resources development team.

The two graduate programmes described above, whilst the only specialist formal programmes leading to higher degrees in water resources topics which are yet available in Australia, do not represent the only University effort in this field. In the last two years a number of related activities have been introduced by other Universities amongst which might be mentioned the hydrologic research programme of the Agricultural Engineering Department at Melbourne University, the project evaluation studies of the University of New England, the post-graduate course in design of water resource systems introduced in 1967 by the University of Auckland, and the Honours option in Hydrology to be introduced in 1968 by the Geography Department of the University of Otago. Whilst all these activities are indicative of an increasing awareness of the importance of education for water resources development, and all contribute substantially to the training of water resources personnel, the special nature of water resources development activities, requiring team effort and an inter-disciplinary approach on a broad hydro-economic front, makes it essential for at least one comprehensive, multi-disciplinary graduates programme to be operated in each country.

A major problem facing the development of educational programmes in the water resources field in both Australia and New Zealand is the availability of personnel. On the one hand, the previous lack of such courses has seriously limited the availability of suitably qualified teaching staff. On the other hand, graduate students are not coming forward in the numbers needed to tackle the breadth and scope of water resources problems awaiting immediate practical solution. In Australia this problem is gradually resolving itself as post-graduate study becomes more popular and Government agencies sponsor graduate studentships. In New Zealand the problem is aggravated by the fact that many post-graduate students prefer to travel overseas for higher degree courses; because New Zealand is such an isolated community there are good reasons for encouraging this trend rather than deploring it.

It is apparent, however, that many overseas teachers and students are anxious to visit Australia and New Zealand, partly because of the special and interesting nature of the water resources problems which these countries have to offer and partly from tourist interests. From the antipodean point of view such visits should be encouraged, as they introduce a flow of ideas and a breadth of experience and interest not otherwise possible. The most important single contribution that any nation can make to water resources development in Australia and New Zealand is to arrange a two-way exchange of university staff and graduate students working in the water resources field. The vital importance of Trans-Tasman exchange and co-operation must also be emphasised in this context. An interesting development in this connection was a post-graduate seminar in Flood Estimation Techniques operated in May 1967 by the University of Canterbury, at which the Principal lecturer was Professor E.M. Laurenson of the University of New South Wales. It is to be hoped that this type of co-operation will continue and expand.

5. CONCLUSION

In this paper an attempt has been made to outline the water resources development problems facing Australia and New Zealand and to explain the special needs these countries have for educational programmes in the water resources field.

The only two specific water resources development programmes taught in Australia and New Zealand universities have been outlined and discussed in relation to what the writer considers to be the essential requirements of an educational programme for the antipodean environment.

It is contended that education for water resources development is best provided at the graduate level. The minimum requirement is a post-graduate diploma of one year's duration which provides formal course work in hydrology, hydro-economics and water resources technology. Where possible this course work should be supplemented by a research project and should culminate in the award of a masterate or Ph.D.

Because of the inter-disciplinary nature of practical water resources development problems, the educational programme should be designed to accept graduates from a variety of disciplines and should engender an inter-disciplinary approach through an emphasis on team activities. It should provide basic core subjects in the fundamental topics of water resources development - hydrology, hydro-economics and water resources technology - but allow for optional subjects permitting the individual student to achieve some depth of specialisation in his own area of interest. If possible it should culminate in the award of a higher degree in the student's own field, so that his identity as an individual specialist is not lost. The objective is to produce a variety of specialists, speaking a common language but each capable of making his own specialised contribution to the activities of a water resources team.

In Australia and New Zealand, where staff and student numbers are limited, considerable flexibility in the educational programme and ample opportunity for individual work are necessary. A major problem facing these countries is academic isolation, and this is particularly applicable to the water resources field. The most important contribution that other nations can make to water resources development in Australia and New Zealand is to foster a two-way exchange of graduate students and water resources specialists.

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